This evaluation of the the dpiX 5-megapixel (2560 x 2048 pixels) 19-inch diagonal monochrome AMLCD was performed by NIDL in support of the NIMA IEC effort to identify and determine suitability of COTS displays for IDEX-II replacement. A NIMA IA evaluation of this dpiX AMLCD was conducted following these measurements at NIDL. About half the IAs liked this monitor for their tasks in an office light ambient. ***Note: dpiX no longer manufactures this monitor.***

EVALUATION of the dpiX 19-INCH DIAGONAL 2560 x 2048 MONOCHROME AMLCD MONITOR

National Information Display Laboratory
at
Sarnoff Corporation
CN 5300, Princeton, NJ 08543-5300

Publication No. 013699-089

August 12, 1999

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
12 Aug 1999	N/A	-

Title and Subtitle Evaluation of the dpiX 19-Inch Diagonal 2560 x 2048 Monochrome AMLCD Monitor	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) National Information Display Laboratory at Sarnoff Corporation CN 5300 Princeton, NJ 08543-5300	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Per conversation with Ronald Enstrom this document is public release, The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 55	

The National Information Display Laboratory

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users.

NIDL is a model project established:

- To help determine U. S. Government needs in the areas of information display, processing, collaboration, and communication
- To locate or stimulate appropriate technology
- To help form partnerships between commercial and noncommercial research and development organizations and technology "consumers"
- To demonstrate to diverse government agencies that they have shared needs and shared solutions
- To help streamline government acquisition of technology by making best use of the commercial marketplace
- To provide ways to stretch limited resources through partnerships and collaborations
- To foster research in advanced capabilities in a manner that provides incentives for commercialization

The NIDL is hosted by the Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics.

CONTENTS

This page intentionally left blank

FOREWORD

The National Information Display Laboratory has performed measurements and prepared this evaluation report which discusses the performance of the following monitor:

dpiX, 19-inch 2048 x 2560 Monochrome AMLCD Monitor

This evaluation was performed in accordance with test procedures developed by the *National Information Display Laboratory* (NIDL). Such objective evaluations are essential to enable medical and government users to obtain, at reasonable cost, display monitors with the required performance.

The following summary pages give the reader an overview of the results. In the interest of brevity, the terms used have not been defined in the summary – this is done in detail in the body of the report and in Appendix A. Two companion documents that describe how the measurements are made, are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*

- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

These procedures were developed in collaboration with the display industry and have been reviewed in EIA and ANSI Committees and with the National Institute of Standards and Technology.

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*

Comments, suggestions and questions about this report or the procedures used are welcome and encouraged. The NIDL can be reached at:

National Information Display Laboratory
P. O. Box 8619
Princeton, NJ 08543-8619
Tel: (609) 951-0150
Fax: (609) 734-2313
e-mail: nidl@nidl.org

Summary Comments on Measurements Performed

The dpiX 5-Megapixel 19-inch Monochrome AMLCD complies with 15 of 16 NIMA IEC (Integrated Exploitation Capability) performance requirements for CRT monitors. In a separate evaluation, 3 of 7 image analysts liked the dpiX monochrome display when used in office lighting. Because of its high luminance and background (black level), the display is well-suited for use in brightly lit environments. It actually may be too bright for use in a dark room.

Table 1. Compliance With IEC Requirements
Monochrome Display - Monoscopic Mode

	Parameter	Required	Measured	Compliance
1.	Dynamic range	25.4 dB	19.2 dB	Fail
2.	Luminance (Lmax)	35 fL	226 fL	Pass
3.	Luminance Uniformity	28%	18%	Pass
4.	Halation	3.5% max.	0.07%	Pass
5.	Luminance Step Response	No visible ringing	No visible ringing	Pass
6.	Addressability minimum	1024 x 1024	2560 x 2048	Pass
7.	Screen Size (Diagonal)	17.5 to 24 inches	19 inches	Pass
8.	Cm-Zone A	35 %	65%	Pass
9.	Cm-Zone B	20 %	65%	Pass
10.	Pixel Shape	Square	0.15 x 0.15 mm	Pass
11.	Pixel density	72 ppi min.	172 ppi	Pass
12.	Warmup Time	30 min to ±50%	30 min to 3%	Pass
		60 min to ±10%	45 min to 1%	
13.	Refresh Rate	72 Hz ±1Hz	71 Hz	Pass
14.	Straightness	0.5% max	Fixed pixels	Pass
15.	Linearity	1% max	Fixed pixels	Pass
16.	Jitter	2 mils max	Fixed pixels	Pass

The dpiX AMLCD exhibits both advantages and disadvantages for image exploitation as discussed in Section III, Analysis and Conclusions. The system tonal transfer characteristic (viewed perpendicular to the screen) is acceptable, exhibiting no black level clipping nor white level saturation, which is an advantage. Several disadvantages are:

- Full screen white-to-black CR measured perpendicular to screen center was only 83.7:1, decreasing further to only 51.3:1 in 500 lux diffuse ambient illumination resulting from effects of screen reflections.
- Response time is typical of AMLCD technology, and so, this LCD probably cannot be used for sequentially-scanned stereo viewing.
- Viewing angle is rather limited.

Evaluation Datasheet

I. MANUFACTURER'S DATA

Manufacturer Name: Model: Monochrome or Color: Image Size (H x V) Screen Diagonal (nominal):	dpiX 5 Megapixel 19-inch AMLCD Monochrome 14.7 x 11.9 inches 19 inches
Addressable Pixel Number: Pixel Size Horizontal Scan Rate: Vertical Scan Rate:	2560 x 2048 5.76 x 5.80 mils (0.146 x 0.147 mm). 186 kHz 71 Hz

II. MEASURED PERFORMANCES

A. Performance Related to Luminance

Warmup Time:	45 Minutes to achieve +/- 1% stability
Full Screen Luminance of White:	226 fL normal to screen center
Full Screen Luminance of Black:	2.7 fL normal to screen center
Contrast Ratio of White to Black	83.7:1 (19.2 dB) normal to screen center 150:1 max. (21.8 dB) at θh = 20°, θv = –24°
Ambient contrast	52:1 (17.1 dB) in 500 Lux
Grille luminance	111.1±0.2 fL for n x n grilles, n= 3, 2, 1 pixels
Luminance Uniformity of White	18% over nine sample points
Luminance Uniformity of Black	47% over nine sample points
Uniformity of Contrast Ratio	48% over nine sample points (CR = 83.7:1 in darkroom at center, normal to screen, and varies from CR = 70.4 to CR = 135:1)
Color Coordinates:	x = 0.339, y = 0.338
Color Uniformity of White:	0.005 delta u'v'
Color Uniformity of Black:	0.055 delta u'v'
Color Tracking:	0.040 delta u'v' (1 to 255 input counts, 3 fL to 226 fL)
System Gamma:	1.62 (39 to 255 input counts, 12.0 fL to 226 fL)
Stability (halation) of Lblack	-7.2% decrease in luminance from full screen to 5% screen
Luminance Stability vs. Fill Factor:	+0.4% increase in luminance from full screen to 5% screen
Screen Reflection Total	17.1% (No antireflection coating)

Evaluation Datasheet (Continued)

B. Performance Related to Resolution

White Line contrast	Horiz	38.5:1 against 2.7 fL black background
	Vert.	36.1:1 against 2.7 fL black background
Black Line contrast	Horiz	5.6:1 against 226 fL white background
	Vert.	4.6:1 against 226 fL white background
White Line luminance	Horiz.	103.9 fL pixel area, 159.6 fL peak
	Vert.	97.5 fL pixel area, 126.4 fL peak
Black Line luminance	Horiz.	40.7 fL pixel area, 27.5 fL peak
	Vert.	48.9 fL pixel area, 30.8 fL peak
1-on/1-off Contrast Modulation (HxV):		65%
1-on/1-off Grille Contrast ratio (HxV):		5:1
Resolvable Pixels (HxV): (screen average)		
@ Cm = 25%, appropriate for imagery		2560 x 2048
@ Cm = 50%, appropriate for text		2560 x 2048

C. Performance Related to Quality

Anomalous nonuniformities:		
	Backlight	14% for white
	Pixel-to-pixel	30% for black
	Mura	Noticeable, mostly on full black screen and dark gray levels
	Special: 10 x 2-pixel V-grille artifact	Cm = +9%, -5% for 2.9 fL to 8.4 fL gray levels
Residual Image (Retention)		White-on-black 60-minute burn-in causes 10% increase in Lblack declining to less than 0.5% after 20 minutes
Shadowing		None visible
Defective pixels		233 stuck pixels, 3 clusters, 2 line defects
Response time		Rise Time = 22mS, Fall Time = 4 mS
Flicker		None (71 Hz refresh)

Evaluation Datasheet (Continued)

D. Performance Related to Viewing Angle

Four-point viewing angles	Lw Lb CR
θh = +45°	174 fL 9.98 fL 17.4
θh = -45°	193 fL 10.8 fL 17.8
θv = +20°	174 fL 4.42 fL 39.4
θv = -30°	186 fL 2.34 fL 79.5
Threshold H & V viewing angles for CR = 40:1	
Horiz	θh = + 30° - 29° for θv = 0°
Vert	θv = + 20°, -37° for θh = 0°
Threshold H & V viewing angles for chromaticity delta u´v´= 0.005	
White Level 255 (100% Lmax)	
Horiz	θh = +15°, -18° for θv = 0°
Vert	θv = +14°, -30° for θh = 0°
Gray Level 017 (2.6 % Lmax)	
Horiz	θh = ± 10 ° for θv = 0°
Horiz	θh = +13°, -15° for θv = -5°
Vert	θv = ± 5 ° for θh = 0°
Viewing cone thresholds for CR = 40:1	
Horiz	θh = ± 44° for θv = -32°
Vert	θv = + 16°, -34° for θh = 0°
Grayscale inversion viewing cone	
Level 255 / level 221 (Lmax / 91%Lmax)	
Horiz	-50° > θh > +50° for -20°< θv < +10°
Vert	θv = +10°, < -50° for θh = 0°
Level 017 / level 000 (2.6 %Lmax / Lmin)	
Horiz	-50° > θh > +50° for -20°< θv < +20°
Vert	θv > +50°,= -26° for θh = 0°
Total Viewing Angle for CR > 40, Δu´v´< 0.015, and no inversion	θh = ± 20° , θv = ± 10°

FLAT PANEL DATA RECORD — SUITE OF BASIC MEASUREMENTS

DISPLAY INFO: Manufacturer: dpiX **Model No:** 5 Megapixel **Serial No:** ______ **Rev. Level:** ______

DESCRIPTION: Diagonal Size: 19 inch **Pixels:** 2560 **(hor) ×** 2048 **(ver) Technology:** AMLCD **Configuration:** ______

PITCH: Horizontal: Pixel: ______ **Subpixel (Dot):** ______ **Other:** ______ **Measurement Direction:** Perpendicular

Vertical: Pixel: ______ **Subpixel (Dot):** ______ **Other:** ______ **Location of Center Meas.:** ______

COLORS: Bits/color: 8 **Color bits:** ______ **Gray Levels:** 256 **Total Colors:** ______ **Signal Source:** SUN **Power Source:** ______

SIZE: Active Area: ___ **(hor) ×** ______ **(ver) LMD: Make:** Photo Research **Model:** PR704 **Serial No:** ______ **Distance:** ______ **AFOV:** _

OVERALL: Dimensions: ______ **(hor) ×** ______ **(ver) Depth:** ______ **Mass (weight):** ______ **Design Viewing Direction:** ______

Test Person: ______ **Date:** ______ **Warm-Up Time:** 45 **min Temperature:** _°C **Run:** _ **Page 1/2**

Full-Screen Center (302-1...4)

	L cd/m²	x	y
White	774	0.339	0.338
Black	9.25	-----	-----
C_R	83.7	No Units for C_R	
Red	n.a.	n.a.	n.a.
Green	n.a.	n.a.	n.a.
Blue	n.a.	n.a.	n.a.

Full-Screen Gray Scale (302-5)

Level	L cd/m²	Opt-16	L cd/m²
Wht-7	774	Wht-15	----
6	695	14	----
5	449	13	----
4	295	12	----
3	171	11	----
2	89.1	10	----
1	37.7	9	----
Blck-0	9.25	8	----
Gamma	0.97		

Shad.=100% $\lvert L_{box}-L_{bkg}\rvert$ / L_{bkg} **(303-4)**

Box at (A-E)	--	Lum. (cd/m²)	
Box (0-7)	--	L_{box}	----
Bkgnd. (0-7)	--	L_{bkg}	----
Shadowing **%**	None visible		

Uniformity: Nonuniformity = 100% x [1-(Min/Max)] (306-1...4)

9 point	5 point	L_w	L_b	C_U	x	y	CCT(K)
1	1	747	5.53	135.1	0.335	0.337	
2		831	6.77	122.7	0.337	0.336	
3	2	739	8.74	84.5	0.332	0.331	
4		714	8.15	87.6	0.335	0.335	
5	3	774	9.25	83.7	0.339	0.338	
6		680	6.68	101.8	0.332	0.332	
7	4	739	10.50	70.4	0.335	0.337	
8		797	8.42	94.6	0.338	0.338	
9	5	702	5.91	118.7	0.333	0.334	
Ave.		747	7.77	99.9	0.335	0.335	
Min.		680	5.53	70.4	0.332	0.331	
Max.		831	10.50	135.1	0.339	0.338	
Nonuniformity		18.2%	47.4%	47.9%	2.06%	2.07%	
Anomalous Low		244	2.24	no data	no data	no data	no data
Anomalous High		284	3.21	no data	no data	no data	no data
Anom. Nonunif.		14.1%	30%	no data	no data	no data	no data

Power Consumption (401-1)

Pattern Used:	Not measured		
Supply	Volts	I(A)	(W)
High	----	----	----
Panel	----	----	----
Low	----	----	----
High	----	----	----
Inverter	----	----	----
	----	----	----
High	----	----	----
Other	----	----	----
Low	----	----	----
High			----
TOTAL			----
Low			----

L-P Performance (402-1)

Input Power, P		
Pattern	White Full Screen	
Voltage	No data	Vdc/ac(rms)
Current	No data	Adc/ac(rms)
Power, P	No data	Wdc/ac(rms)
Output Luminance, L_w		
L_w	No data	cd/m²
Result: L-P Performance		
L_w / P	No data	cd/m²W

Response Time (305-1)

Blk-Wht	22	ms
Wht-Blk	4	ms
Total	26	ms

Ambient Contrast

White L_{AW}	858	L_w	760	L_b	9.38	L'_w	823	L'_b	11.8
Black L_{AB}	44.3	Law	766	La_b	14.9	L_{std}	864	ρ_{std}	.925
C_A	52:1	E	2935			E_L	500		

Viewing Angle (307-1 or 2)

Direct'n	Angle	White (cd/m²) L_w	x_w	y_w	CCT(K)	Black (cd/m²) L_b	x_b	y_b	C_R	Red L_{red}	x_{red}	y_{red}	Green L_{grn}	x_{grn}	y_{grn}	Blue L_{blu}	x_{blu}	y_{blu}
Up θ_U	20	596				15.1			39.4									
Dwn θ_D	30	637				8.02			79.5									
Right θ_R	45	596				34.2			17.4									
Left θ_L	45	661				37.0			17.8									

Comments:

FLAT PANEL DATA RECORD — SUITE OF BASIC MEASUREMENTS

Section I INTRODUCTION

The present study evaluates a production unit of the *dpiX, 19-inch diagonal 2560 x 2048 Monochrome* high-resolution AMLCD monitor. dpiX provided the 5-megapixel medical monitor and SUN graphics driver as a system (display, dpiX graphics board, software). The test signals were obtained from this board to give a full representation of the dpiX system. NIDL provided the use of the photometric test equipment.

Only photometric measurements were performed on this system. No electrical measurements were made.

This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

Non-technical users may wish to refer to the Measurement Term Definitions, given in Appendix A, to understand the implications of particular measurement results. The technical user will most likely utilize the Evaluation Datasheet and Measurement Summary, referring to the measurement details and analyses when appropriate.

We provide below a description of the monitor that was evaluated and the details of the setup procedures used to prepare the monitor for measurement. Section II presents the data and results of the photometric measurements. Section III completes the report with analyses of the measurements and final conclusions.

Appendices A and B provide pertinent definition of terms and discuss the concepts of colorimetry.

Procedures and calibrations used in the measurements are based on methods standardized by the Video Electronics Standards Association (VESA):and are found in the VESA Standard:

FPDM-1 Flat Panel Display Measurements Standard, Version 1.0, VESA, May 1998.

Additional procedures and calibrations used in the measurements are detailed in the NIDL documents,

Display Monitor Measurement; Methods under discussion by EIA (Electronic Industries Association) Committee JT-20, Part 1: Monochrome CRT, Monitor Performance, Draft Version 2.0, July 12, 1995.

and

Display Monitor Measurement; Methods under discussion by EIA (Electronic Industries Association) Committee JT-20, Part 2: Color CRT, Monitor Performance, Draft Version 2.0, July 12, 1995.

Each measurement described in Section II is referenced to one of these documents.

A. The dpiX, 2048 x 2560 Monochrome AMLCD Monitor

According to the manufacturer, the specifications of the 19-inch dpiX, 2048 x 2560 monochrome AMLCD monitor include:

Photometric Parameters:

- Display format is 2048 x 2560 addressable pixels.
- Screen diagonal (nominal) is 19 inches.
- Addressable pixel size is 5.76 x 5.80 mils (0.146 x 0.147 mm).
- Luminance is 226 fL.

Electrical Parameters:

- Line rate is 186 kHz.
- Field rate is 71 Hz, non-interlaced.
- Video data rate is 500 MHz.
- Pixel time is 2 nsec.

B. Initial Monitor Set Up

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 3.0, p.17.

The monitor was set up at the factory before shipment. A representative of dpiX was invited to participate and join in the set up and initial measurements at NIDL, but chose not to. No user adjustments were possible.

Section II PHOTOMETRIC MEASUREMENTS

Reference: VESA FPDM Flat Panel Display Measurements, Section 300, page 11.
Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

Instruments used in these measurements included:

- Photo Research SpectraScan PR-704 spectroradiometer
- Microvision Display Characterization System which included:
  - Superspot 100
  - Spotseeker Positioner
  - OM-1 optic module (Two dimensional photodiode linear array device, projected element size at screen is 0.5 mils with photopic filter).
  - OM-5 optic module (Two dimensional charge-coupled linear array device, projected element size at screen is 0.2 mils with photopic filter).
  - Superspot 220 Goniometer Spectroradiometer

This page intentionally left blank

A. WARMUP CHARACTERISTICS

Reference: VESA FPDM Flat Panel Display Measurements, Section 305-3, p89.
Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.1, p. 11.

A 45 minute warmup was necessary for luminance stability (+/- 1.0%).

The luminance of the screen (commanded to 100% white) was monitored for 120 minutes after a cold start. Measurements were taken every minute. A subset of the data is presented in Table II.A-1. Figure II.A-1 shows the data in graphical form. The luminance remains very stable after 45 minutes.

Table II.A-1. Warmup Characteristics (fL)

Minutes	Luminance	Minutes	Luminance	Minutes	Luminance
1	136	15	224	60	225
2	173	20	229	70	224
3	187	25	232	90	224
4	192	30	230	100	223
5	198	40	227	110	223
10	216	50	226	120	223

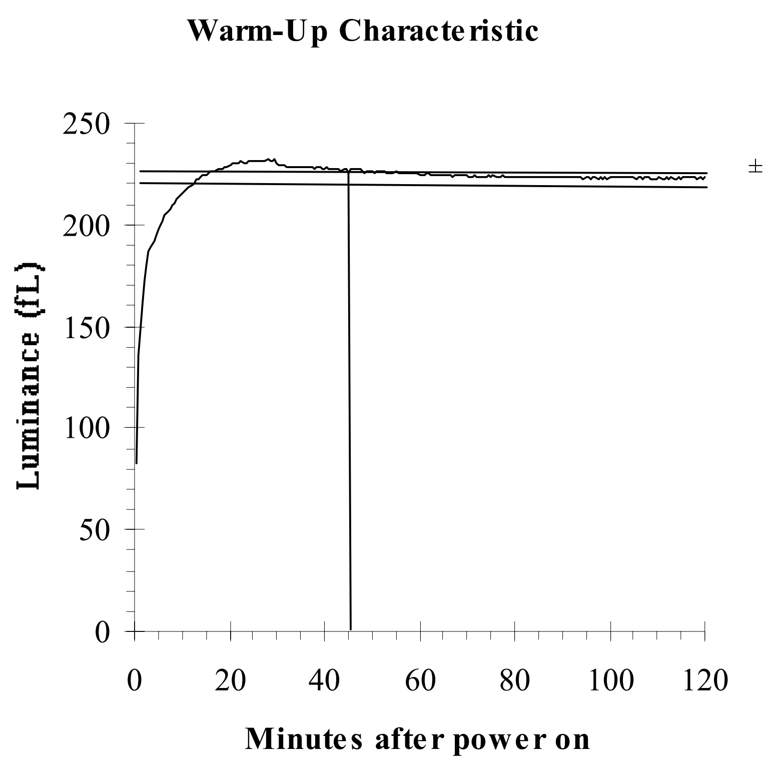


Figure II.A-1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 255.

B. LUMINANCE AND COLOR UNIFORMITY

Reference: VESA FPDM Flat Panel Display Measurements, Section 306, p95.
Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

The highest luminance setting of 226 fL measured at screen center varied by up to 18% across the screen. Chromaticity variations were less than 0.005 delta u'v' units. The lowest luminance setting of 2.7 fL measured at screen center varied by up to 47% across the screen. Chromaticity variations were as much as 0.055 delta u'v' units. Combined luminance non-uniformity for white and black led to a non-uniformity for contrast ratio, CR, of 48%. (CR = 83.7 in darkroom at center, normal to screen.)

Luminance and CIE x, y chromaticity coordinate measurements were taken at nine screen positions for three luminance settings for a full screen test pattern. White to black contrast ratio was then computed for each screen position. 9-point sampled data (center, 4 corners, 6,12,3 and 9 in Figure II.B-1) reveal maximum variations encountered in full 25-point sampling. The data for nine screen positions are shown in Table II.B-1. Figures II.B-2 and II.B-3 show the luminance and chrominance data in graphical form.

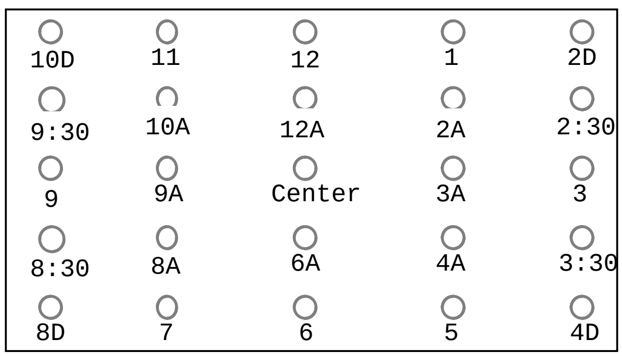


Fig.II.B-1. 25 Screen Test Points
Peripheral points are located inward from the edge of the image area by 10% of the screen size.

Table II.B-1.Spatial Uniformity of Luminance, Color, and Contrast Ratio

Color and luminance (in fL) for three luminance settings taken at nine screen positions (in % of Lmax).

	Full screen at 100% Lmax			Full screen at 50% Lmax		
POSITION	**x**	**y**	**fL**	**x**	**y**	**fL**
center	0.339	0.338	226.0	0.317	0.279	113.0
2	0.332	0.331	215.7	0.308	0.272	103.4
3	0.332	0.332	198.4	0.310	0.274	97.8
4	0.333	0.334	204.8	0.310	0.274	101.6
6	0.338	0.338	232.5	0.316	0.278	113.6
8	0.335	0.337	215.7	0.311	0.275	105.5
9	0.335	0.335	208.3	0.312	0.276	104.4
10	0.335	0.337	218.1	0.312	0.275	106.0
12	0.337	0.336	242.5	0.317	0.280	116.0

	Full screen at Lmin			Contrast Ratio, Lmax/Lmin
center	0.289	0.286	2.70	83.7
2	0.233	0.227	2.55	84.6
3	0.264	0.260	1.95	101.7
4	0.273	0.270	1.73	118.4
6	0.272	0.270	2.46	94.5
8	0.240	0.241	3.07	70.3
9	0.267	0.266	2.38	87.5
10	0.267	0.264	1.61	135.5
12	0.270	0.265	1.98	122.5

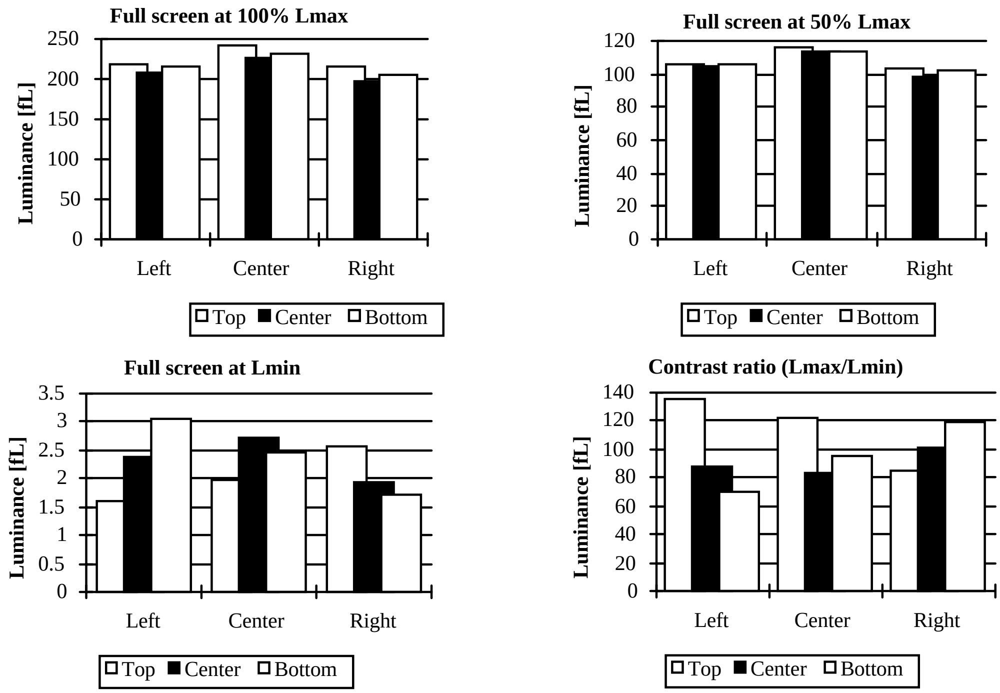


Fig.II.B-2. Spatial Uniformity of Luminance and Contrast Ratio

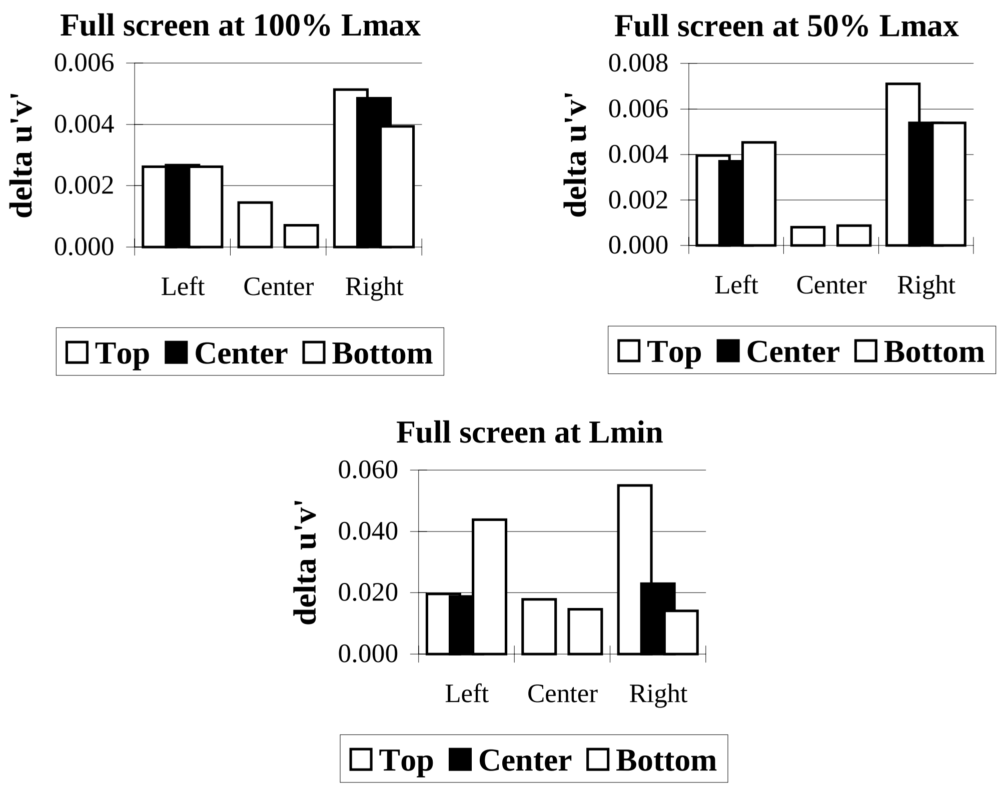


Fig.II.B-3. Spatial Uniformity of Chromaticity Error Relative to Screen Center. Note the large change in chromaticity, *as much as 0.055 delta u'v' units* at the Lmin luminance setting. (Delta u'v' of 0.004 is just visible.)

C. ANOMALOUS NONUNIFORMITY

Reference: VESA FPDM Flat Panel Display Measurements, Section 306, p95.
Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28

The luminance varied by up to 14% along the minor axis (6 to 12 o'clock positions) of the screen. This non-uniformity may be due primarily to the back light. Pixel-to-pixel peak luminance variations for full black exceeded 30%. Contrast modulation, Cm, of a vertical grille artifact was as high as Cm = 9%.

The anamolous luminance non-uniformities in addition to visible mura were quantified and associated with the backlight, the liquid crystal active matrix, and electrical signal connections.

To evaluate the backlight, luminance was measured at many points along the minor axis of the screen to quantify a visible luminance non-uniformity. The luminance varied by up to 14% along the minor axis of the screen [100% x (284 fL - 244 fL) / 284 fL]. This variation may be due primarily to the back light. The data are listed in Table II.C-1 and plotted in Figure II.C-1.

To quantify the nonuniformity of the active matrix liquid crystal, pixel-to-pixel area luminance variations shown in Figures II.C-2a through 2c for a black full screen were measured on a rectangular sample area of 6 columns and 5 rows of pixels. Luminance varied from 2.24 fL to 3.21 fL, so the variation exceeded 30%. The data for this measurement are listed in Table II.C-2.

To quantify the effects of the electrical signal, contrast modulation of vertical grille artifacts were measured for various gray levels and were found to be as high as Cm = 9% for a 6 fL gray level. The cause of this artifact is thought by dpiX to be due to bit loss caused by poor signal cabling. The data are presented in Table II.C-3 and Figure II.C-3.

Table II.C-1.Spatial Uniformity of Luminance of White

Position (mm)	Luminance (fL)
2	275
8	284
32	264
100	244
135	254
145	250
163	255
180	255
198	263
215	256
225	258
235	255
270	274
275	276
290	280
295	264
298	244
Min	244
Max	284
Nonuniformity	14%

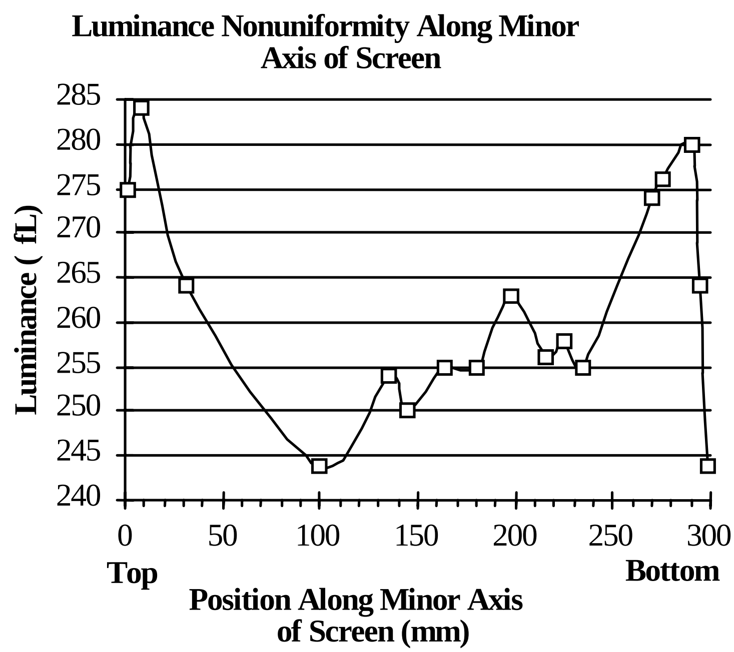


Fig.II.C-1. Spatial Uniformity of Luminance of White

Table II.C-2. Pixel-to-Pixel Uniformity of Luminance of Black

Luminance (fL) aranged in table according to pixel position on screen.

Pixel luminance (fL) of 6H x 5V pixel sample				
2.40	2.31	2.46	2.40	2.42
2.28	2.31	2.68	2.38	2.33
2.29	2.29	2.45	2.41	2.36
2.24	2.42	2.47	3.03	2.60
2.38	2.48	2.91	2.53	2.27
2.37	3.21	2.66	2.62	2.38
	Min	2.24		
	Max	3.21		
Nonuniformity		30%		

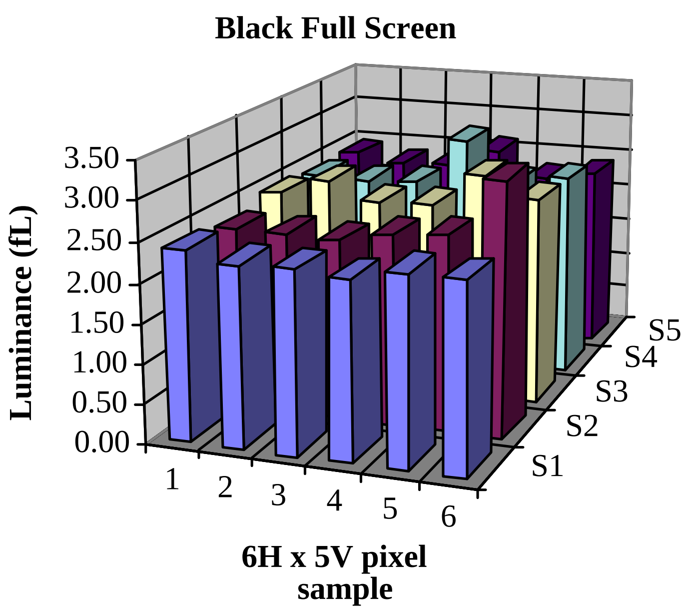


Fig.II.C-2a. Graphical representation of peak luminance of individual pixels of Table II.C-2 above measured over a 6 H x 5V pixel area with PR1980 spot photometer using 2-minute aperture with close-up lens.

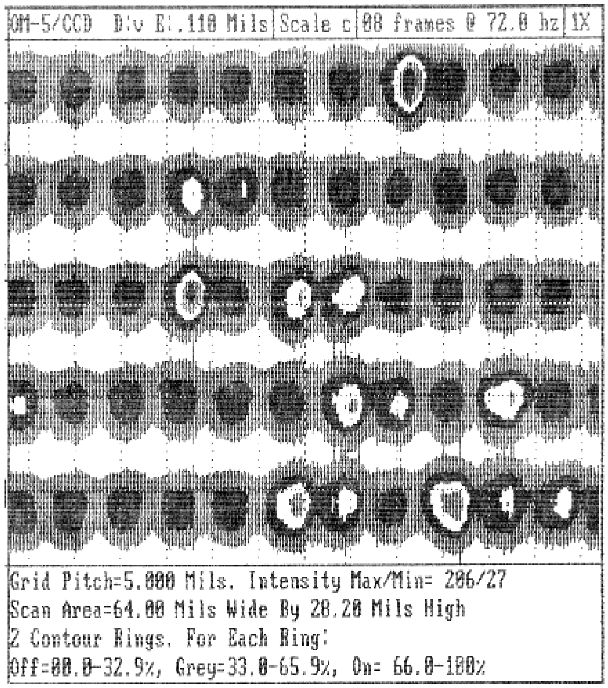


Fig.II.C-2b. Luminance contour plots of individual pixels measured using a Microvision CCD array detector.

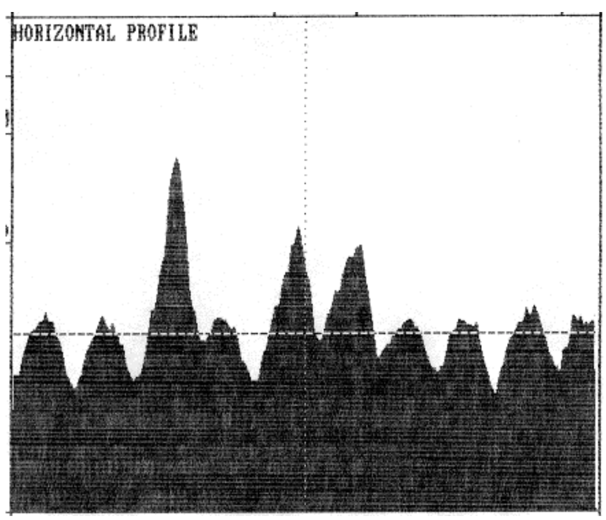


Fig.II.C-2c. Horizontal luminance of individual pixels obtained by taking cross-section of luminance contour plot shown in Figure II.C-2b above measured using a Microvision CCD array detector.

Table II.C-3. Luminance and Contrast of Grille pattern Artifact

Input Count Level	Luminance (fL) of 10-pixel/2-pixel Vertical Stripe Artifact			
	10-pixel wide stripe	2-pixel wide stripe	Difference (fL)	Cm(%)
0	2.08	1.98	0.10	2.5%
1	2.18	2.40	-0.22	-4.8%
2	2.30	2.53	-0.23	-4.8%
3	2.41	2.65	-0.24	-4.7%
7	2.90	2.47	0.43	8.0%
15	4.11	3.99	0.12	1.5%
23	5.33	4.77	0.56	5.5%
31	6.75	5.63	1.12	9.0%
39	8.42	7.69	0.73	4.5%
47	10.4	10.2	0.13	0.6%
63	14.6	14.5	0.11	0.4%
79	19.9	19.8	0.09	0.2%
95	26.3	26.3	0.00	0.0%
111	33.8	33.7	0.10	0.1%
127	42.8	42.7	0.10	0.1%

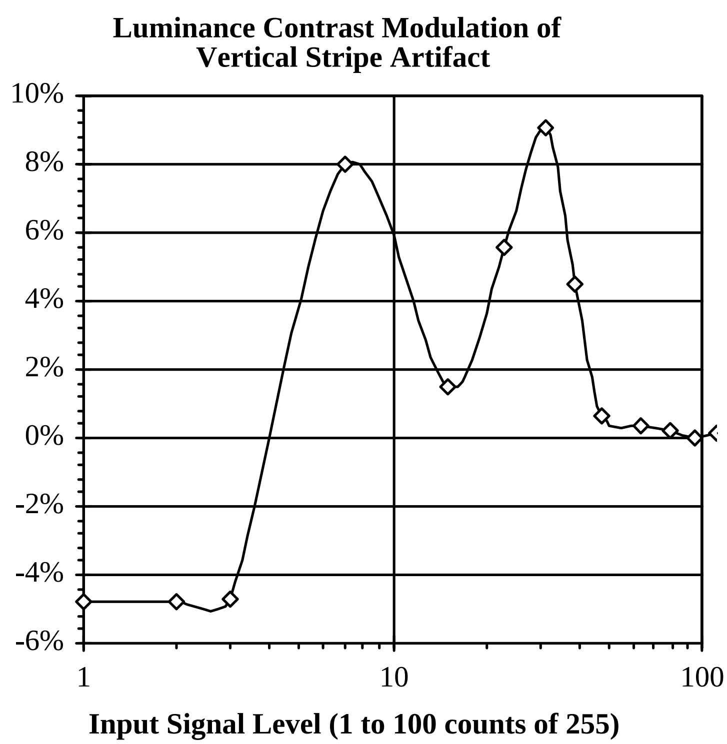


Fig.II.C-3. Contrast modulation of vertical grille artifact varied by gray level and was as high as Cm = 9% for a 6 fL gray level. The cause of this artifact is thought by dpiX to be due to bit loss caused by poor signal cabling. This artifact was not visually significant above input levels above 95.

D. LUMINANCE STABILITY vs. FILL FACTOR

Reference: VESA FPDM Flat Panel Display Measurements, Section 304-8, p80.
Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.3, p. 26.

Luminance decreases by up to 7.2% for black on white, and increases by up to 0.4% for white on black, as the target size is decreased from full screen to 5% of full screen size.

Center screen luminance was measured for different-sized white patches on a black background (different fill factors) and for different-sized black patches on a white background. The data are displayed in Table II.D-1 below and shown graphically in Figure II.D-1.

Table II.D-1. White Luminance Stability vs. Fill Factor
Luminance (fL) at center screen for different size patches.

Patch % screen size	Lblack on white fL	Lwhite on black fL	Change Lblack on white	Change Lwhite on black
0	224	2.947		
5	3.171	226.3	-5%	0.40%
10	3.229	226.6	-7%	0.26%
15	3.233	226.2	-7%	0.44%
20	3.231	226.7	-7%	0.22%
25	3.231	226.6	-7%	0.26%
30	3.175	226.9	-5%	0.13%
35	3.165	226.5	-5%	0.31%
40	3.167	226.6	-5%	0.26%
45	3.174	226.9	-5%	0.13%
50	3.167	226.5	-5%	0.31%
55	3.158	226.9	-5%	0.13%
60	3.119	227.2	-4%	0.00%
65	3.109	226.8	-3%	0.18%
70	3.111	226.9	-3%	0.13%
75	3.102	226.6	-3%	0.26%
80	3.094	227	-3%	0.09%
85	3.083	226.9	-2%	0.13%
90	3.067	227.3	-2%	-0.04%
95	3.048	227.3	-1%	-0.04%
100	3.01	227.2	0%	0.00%

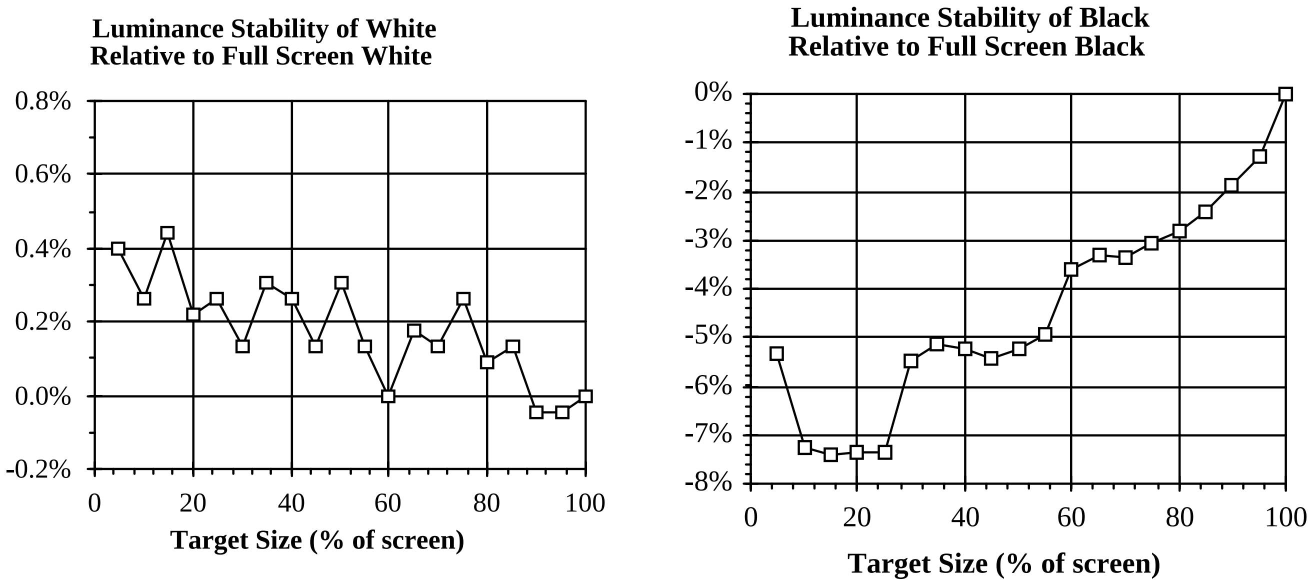


Fig.II.D-1. The change in luminance of white and black as a function of screen fill factor.

E. SYSTEM TONAL TRANSFER

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.2, p. 23.
VESA FPDM Flat Panel Display Measurements, Section 302-5, p44.

No black level clipping nor white level saturation were observed. Gray scale full screen gamma is 1.62 along the linear region between input counts 39 to 255 (12.0 fL to 226 fL). Chromaticity varies by delta u´v´ = 0.04 between levels 1 to 255.

Luminance at center screen for a 100% screen size box (full screen white) was measured perpendicular to the screen for 20 different input counts. Table II.E-1 shows the data, and Figure II.E-1 shows the System Tonal Transfer curve of luminance at center screen as a function of input counts. System Gamma is defined as the slope of the curve, in a log-log plot. Since the curve may be nonlinear, a unique value of gamma may not exist. Values were derived for the linear luminance range (95 to 159 input count levels). The shift in whitepoint chromaticity over the full range of input levels reached 0.04 delta u'v'. This data is plotted in Figure II.E-2.

Table II.E-1. System Tonal Transfer - Drive versus Luminance (fL)

Input	Luminance	Chormaticity Coordinates		Whitepoint
Count	fL	CIE x	CIE y	CCT
0	2.712	0.286	0.2774	10029
1	2.961	0.2873	0.2788	9773
2	3.118	0.288	0.2795	9643
3	3.271	0.2887	0.2802	9528
7	3.702	0.2903	0.2817	9273
15	5.398	0.294	0.2856	8701
23	7.077	0.2961	0.2875	8429
31	9.447	0.2977	0.2889	8230
39	11.95	0.299	0.2904	8064
47	15.46	0.3001	0.2916	7936
63	21.98	0.3016	0.2928	7782
79	30.2	0.3028	0.2941	7654
95	40.5	0.3041	0.2956	7509
111	51.75	0.3056	0.2974	7353
127	66.46	0.3071	0.2992	7206
143	83.02	0.3092	0.3018	7012
159	102.2	0.3114	0.3044	6818
191	145.5	0.3175	0.3119	6349
223	209.6	0.3292	0.3255	5653
255	226.1	0.3333	0.3299	5451

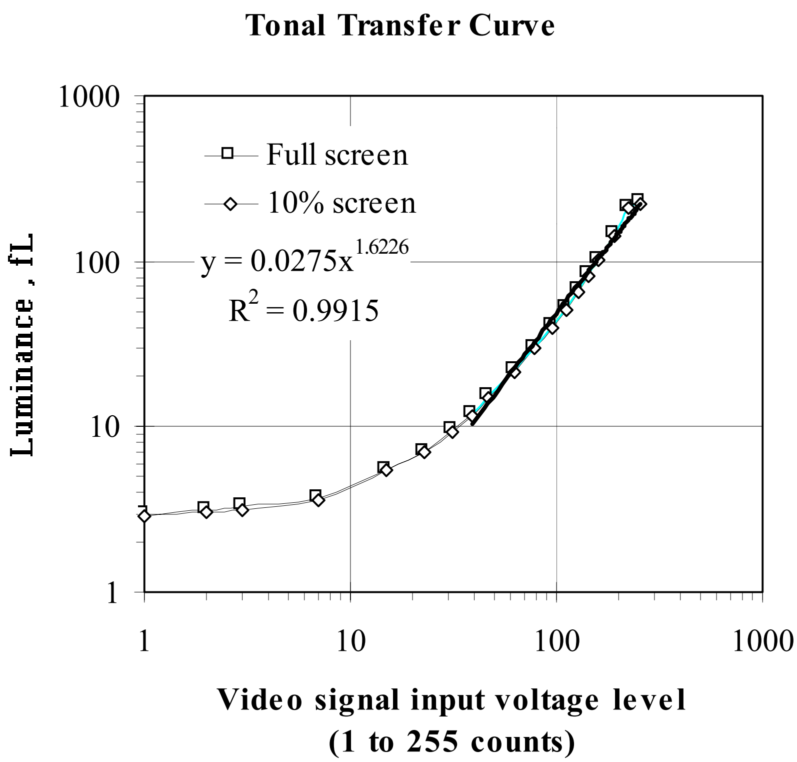


Fig. II.E-1. System Tonal Transfer at center screen as a function of input counts.

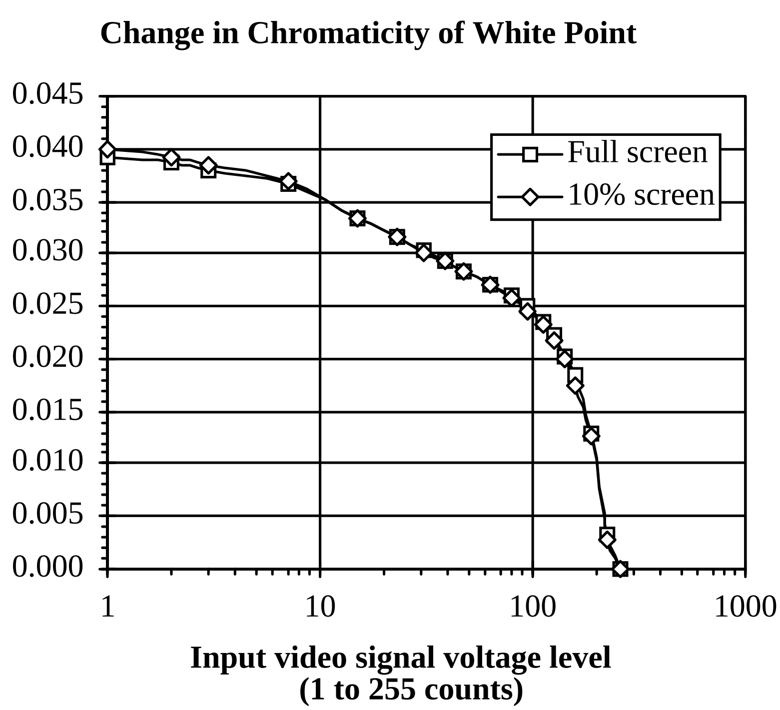


Fig. II.E-2 e reference white point value is 255 counts.

F. LUMINANCE RESPONSE TIME

Reference: VESA FPDM Flat Panel Display Measurements, Section 305-1, page 84.

Rise time of Black to White was 22mS, fall time of White to Black was 4 mS.

The switching speed of the liquid crystal is assessed by measuring the change in luminance as a function of time. The response of the transition from a black full screen to a white full screen is the rise time. The response of the transistion from a white full screen to a black full screen is the fall time. The time interval is measured from the 10% to 90% of steady state luminance. Periodic variations in luminance are filtered from the luminance profile mathematically using a moving window filter set to the refresh rate of the display. The data are displayed in Figure II.E-1.

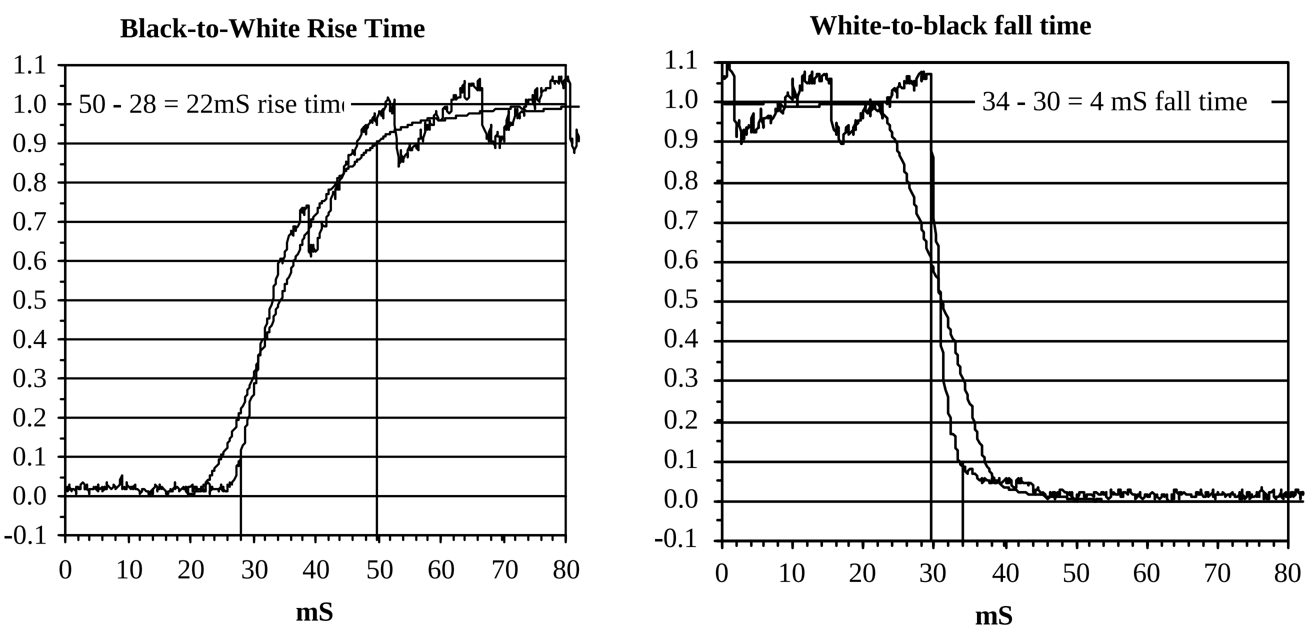


Fig. II.F-1 The response time is shown for transitions from a black full screen to a white full screen (rise time) and from a white full screen to a black full screen (fall time) measured from the 10% to 90% of steady state luminance. Periodic variations are filtered using a moving window.

G. RESIDUAL (LATENT) IMAGE

Reference: VESA FPDM Flat Panel Display Measurements, Section 305-2, page 87.

A white-on-black 60-minute burn-in causes residual image retention amounting to a 10% increase in luminance of black. The increase in luminance stabilizes to within 0.5% after 20 minutes.

To evaluate the effects of long-term static images, a high-contrast white-on-black image is displayed continuously for a 60-minute burn-in period, and then removed. In this case, residual image retention resulted in a 10% increase in luminance of black from 2.7 fL to 3.0 fL. The black level luminance returned to the pre-burn-in level after the white patch was removed, and stabilized to within 0.5% of the final luminance value after 20 minutes.

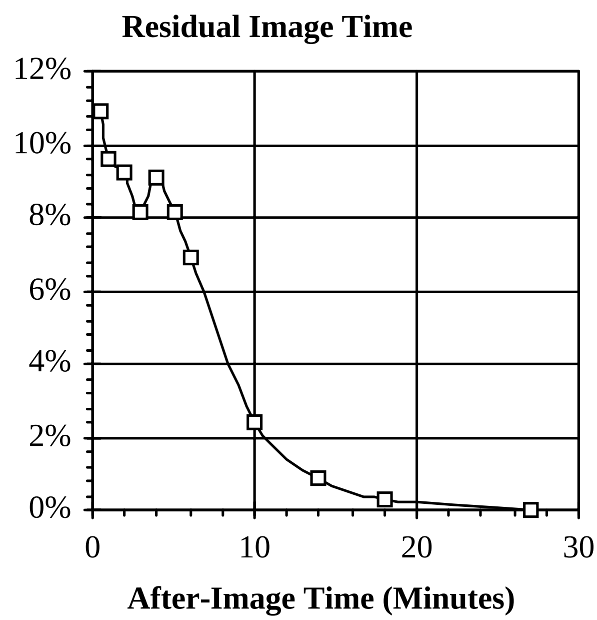


Fig. II.G-1. Black-level luminance as a function of time after burn-in image was removed.

H. H & V VIEWING ANGLES

Reference: VESA FPDM Flat Panel Display Measurements, Sections 307-1,2, page 106.

Horizontal and vertical threshold viewing angles at which the white to black contrast ratio was 40:1 were θh = + 30°, -29° for θv = 0° and θv = + 20°, -37° for θh = 0°.

The white to black contrast ratio at arbitrary four-point H & V viewing angles was less than 18:1 at horizontal viewing angle of +/-45°, 39.4: 1 at a vertical viewing angle of 20°, and 79.5:1 at a vertical viewing angle of -30°.

Luminance of full screen gray scales was measured at screen center as a function of horizontal viewing angle with vertical angle set perpendicular to the screen, and as a function of vertical viewing angle with horizontal angle set perpendicular to the screen. The luminance data are plotted in Figure II.H-1. From this data, threshold H & V viewing angles where contrast ratio was 40:1 were determined using linear interpolation. This data was also used to determine values of contrast ratio at four arbitrary H & V viewing angles (two vertical angles up and down, and two horizontal angles right and left) for use in pass / fail quality testing.

Note: H&V viewing angle measurements are restrictive and do not necessarily include the design viewing angle, and therefore may not produce the best luminance or contrast ratio for the display. See the following section on viewing cones for a more complete representation of the display's performance.

Table II.H-1 Threshold H&V Viewing Angles

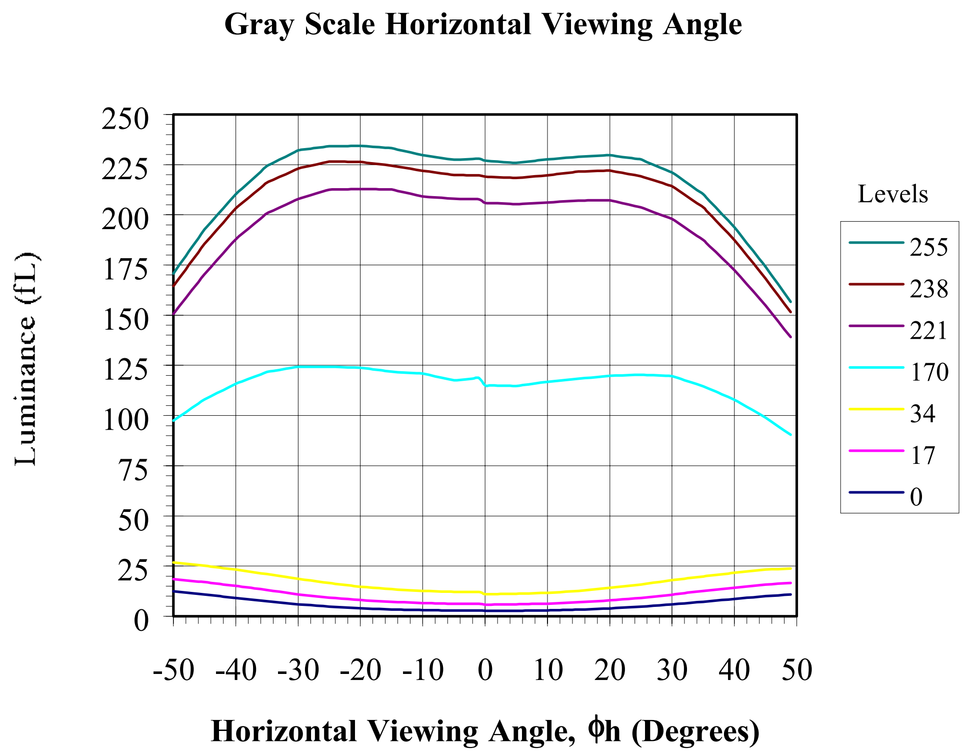
Angles measured for contrast ratio threshold = 40:1 (White-to-Black)

Direction	Angle	Lwhite (fL)	Lblack (fL)	Contrast Ratio
Up	20°	176	4.4	40:1
Down	-37°	160	4.0	40:1
Right	30°	232	5.80	40:1
Left	-29°	223	5.60	40:1

Table II.H-2 Four-Point H&V Viewing Angles

Contrast ratios measured at specified angles.

Direction	Angle	Lwhite	Lblack	Contrast Ratio
Up	20°	174	4.42	39.4:1
Down	-30°	186	2.34	79.5:1
Right	45°	174	9.98	17.4:1
Left	-45°	193	10.8	17.8:1



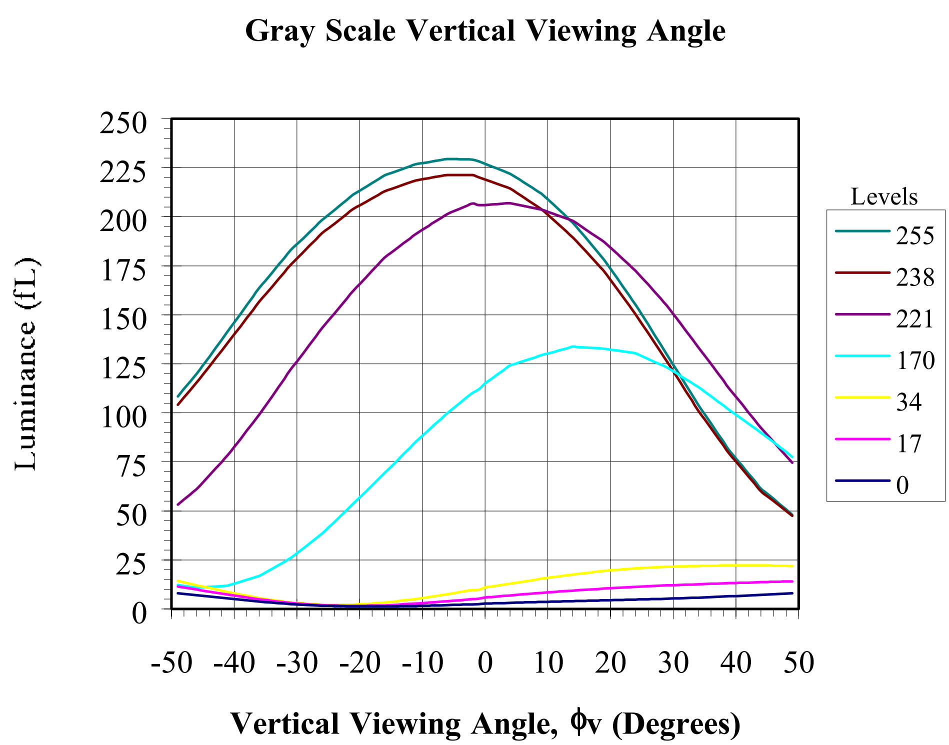


Fig. II.H-1. Gray scale luminance in fL as a function of horizontal and vertical angles of view.

I. VIEWING CONE THRESHOLDS

Reference: VESA FPDM Flat Panel Display Measurements, Sections 307-4, page 111.

Horizontal and vertical viewing angles from which the white to black contrast ratio decreased to 40:1 were θh = ± 44° for θv = -32° and θv = + 16°, -34° for θh = 0°. Threshold H & V viewing angles for chromaticity delta u´v´= 0.005 were θh = +15°, -18° for θv = 0° and θv = +14°, -30° for θh = 0° for White Level 255 (Lmax), and θh = ± 10 ° for θv = 0°, θh = +13°, -15° for θv = -5°, and θv = ± 5 ° for θh = 0° for Gray Level 017 (2.6% Lmax).

Luminance and chromaticity of a white full screen and of a dark gray full screen were measured at screen center as a function of both horizontal and vertical viewing angles. Luminance of a black full screen was also measured over the same range of viewing angles. Contour plots of the white and black luminance viewing cones are presented in Figure II.I-1. From this data, the white-to-black contrast ratio was computed at each angle and shown in the contour plot in Figure II.I-2. Contour plots of the chromaticity viewing cones are shown for white and gray in Figure II.I-3.

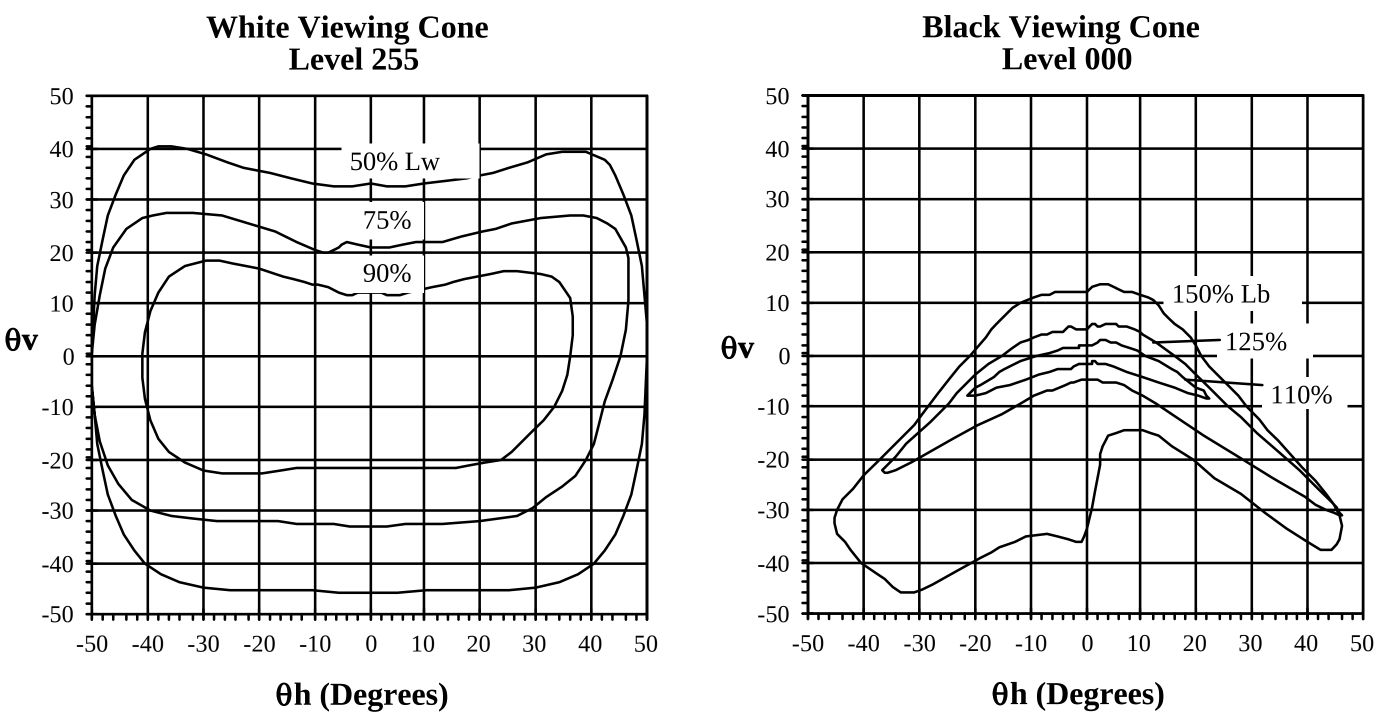


Fig. II.I-1 Lmax was 226 fL and Lmin was 2.7 fL measured perpendicular to the screen.

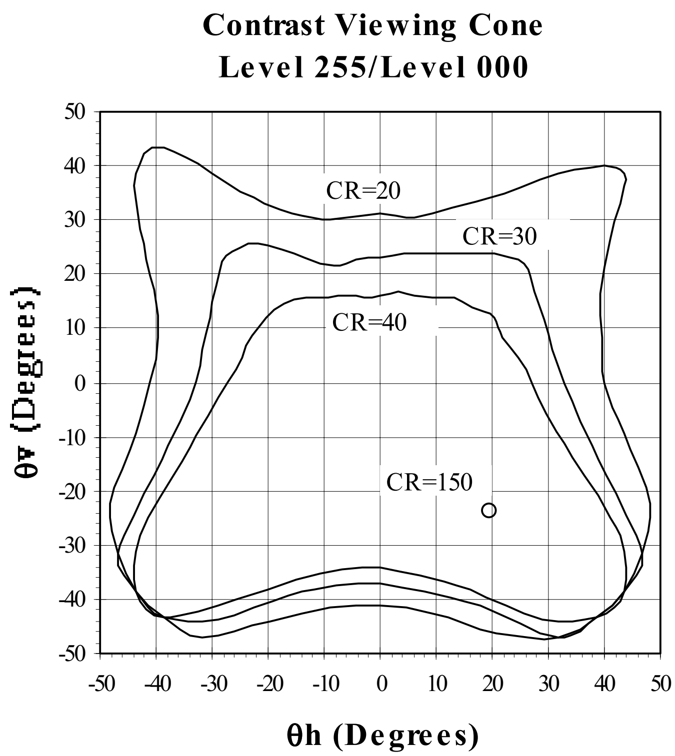


Fig. II.I-2 Max. CR = 150 at θh = 20°, θv = -24°).Threshold H & V viewing angles for chromaticity delta u´v´=0.005 are: θh = +15°, -18°, θv = +14°, -30° for white (Lmax) and θh = ± 10 °, θv = ± 5 ° for gray level 017 (2.6% Lmax).

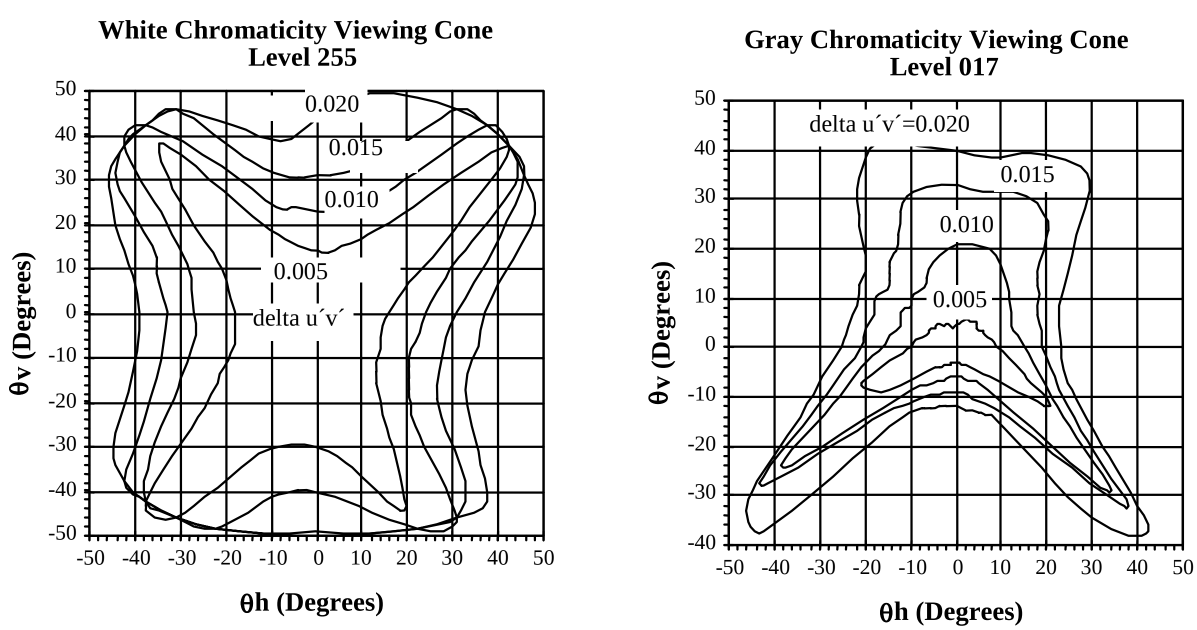


Fig. II.I-3. Viewing Cone Measurements of Chromaticity of White and Dark Gray

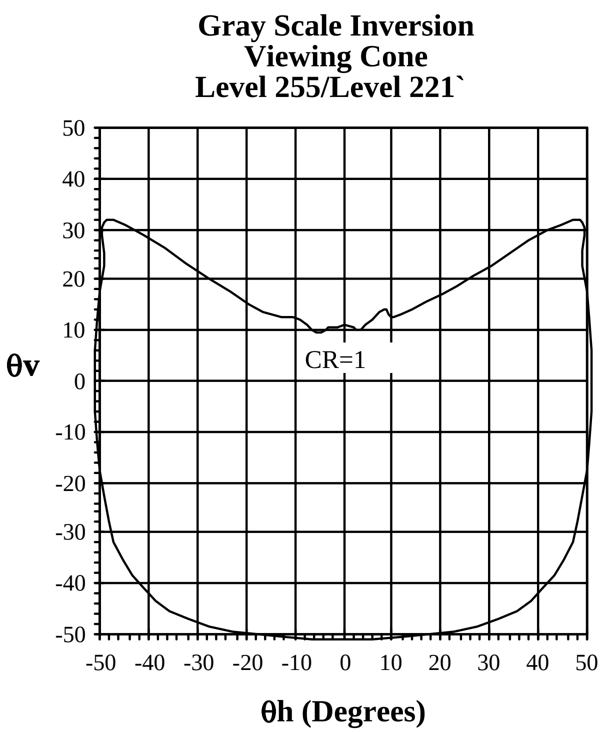
J. GRAYSCALE INVERSION VIEWING CONE

Reference: VESA FPDM Flat Panel Display Measurements, Sections 307-5, page 113.

Horizontal and vertical viewing angles from which the grayscale inversion occurs between levels 255 and 221 (Lmax/91%Lmax) were -50° > θh > +50° for -20°< θv < +10° and θv = +10°, < -50° for θh = 0°.

Horizontal and vertical viewing angles from which the grayscale inversion occurs between levels 017 and 000 (2.6%Lmax/Lmin) were -50° > θh > +50° for -20°< θv < +20° and θv > +50°,= -26° for θh = 0°.

Gray scale inversion viewing cones for light and dark gray levels 255, 221, 017 and 000 produce 226fL (Lmax), 206 fL (91% Lmax) , 5.8 fL (2.6% Lmax) and 2.7 fL (Lmin), respectively, measured normal to screen at screen center. Level 255 (Lmax) inverts with level 221 (91%Lmax) at Vertical angle, θv = +12°. Level 017 (2.6%Lmax) inverts with level 000 (Lmin) at Vertical angle, θv = -26°.



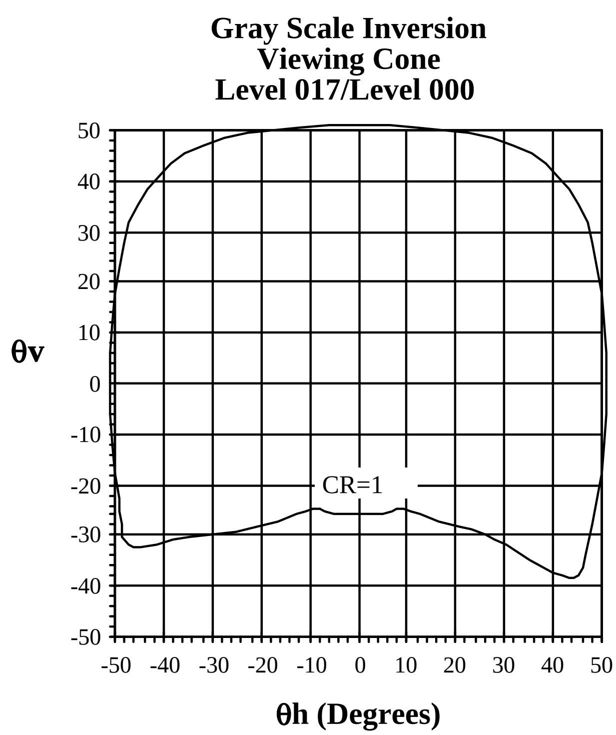


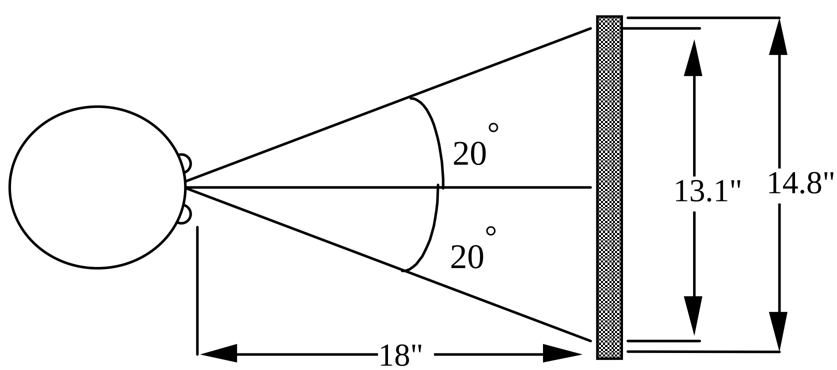
Fig. II.J-1. Gray Scale Inversion Viewing Cones for Light and Dark Gray Levels 255, 221, 017 and 000.

K. TOTAL VIEWING ANGLE

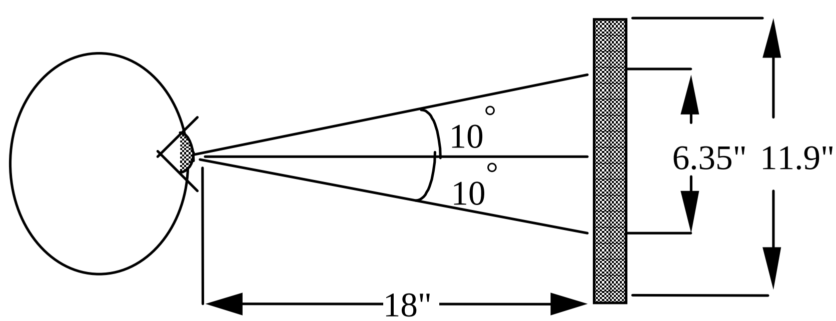
Reference: None.

The total usable viewing angle range is limited to θh = ± 20° and θv = ± 10°, spanning 47% of the total area of the screen at a viewing distance of 18 inches assuming the following four constraints:
1) Maintain white-to-black contrast ratio of at least 40:1
2) Limit chromaticity shift delta u´v´ to less than 0.015
3) Avoid gray-scale inversion between level 255 and level 221 (Lmax/91%Lmax)
4) Avoid gray-scale inversion between level 017 and level 000 (2.6%Lmax/Lmin)

The combined viewing angle results for contrast ratio, gray scale inversion, and chromaticity shift are considered for determining a practical view angle range over which this display performs adequately for all performance parameters.



Top View



Side View

Fig. II.K-1. Total horizontal and vertical viewing angle range at a viewing distance of 18 inches, θh = ± 20°, θv = ± 10° spans 47% of total area of screen.

L. LINE CONTRAST

Reference: VESA FPDM Flat Panel Display Measurements, Sections 303-1, page 53.

Contrast ratio of white lines on a black background was 38.5:1 x 36.1:1 (H x V). Contrast ratio of black lines on a white background was 5.6:1 x 4.6:1 (H x V).

The line luminance profiles of vertical and horizontal white lines were measured at screen center with the full screen luminance set at maximum level (226fL, 100%Lmax) for the black line (Lmin) measurement, and with the full screen luminance set at minimum level (2.7 fL, Lmin) for the white line measurement. The data are displayed in Table II.L-1. Line contrast is determined for the filtered luminance profiles using moving window averaging as depicted in Figure II.L-1. The size of the moving window is one pixel.

Table II.L-1. Line luminance and Contrast Ratio
Vertical and horizontal white and black lines measured at screen center.

	White Line Luminance		**Black Line Luminance**	
	Horiz. Line	**Vert. Line**	**Horiz. Line**	**Vert. Line**
Peak Luminance	159.6 fL	126.4 fL	27.5 fL	30.8 fL
Pixel Area Luminance	103.9 fL	97.5 fL	40.7 fL	48.9 fL
Background Luminance	2.7 fL	2.7 fL	226 fL	226 fL
Area Contrast Ratio	38.5:1	36.1:1	5.6:1	4.6:1

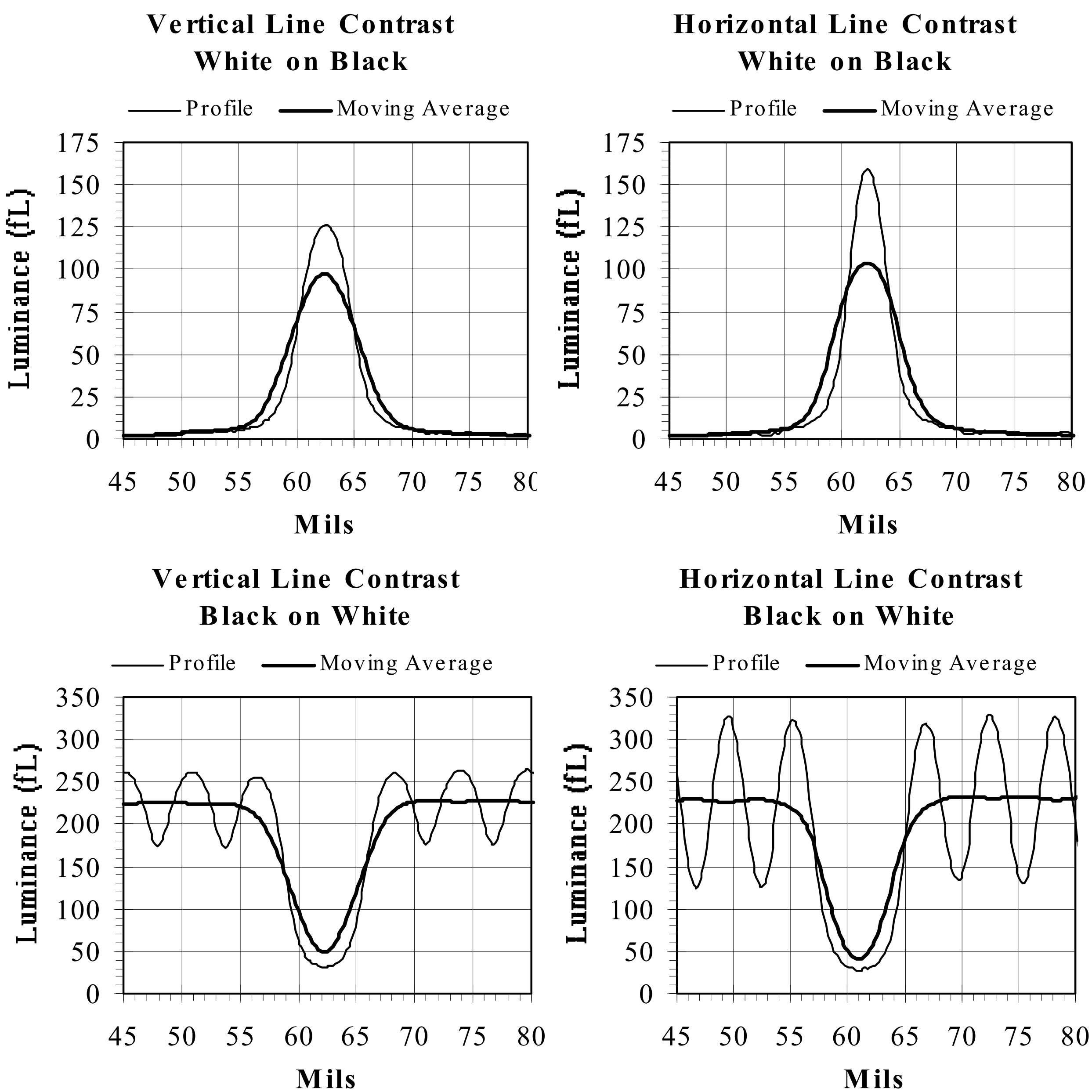


Figure II.L-1 Line luminance profiles in fL (raw and filtered) of vertical and horizontal white lines on black backgrounds and black lines on white backgrounds.

M. GRILLE CONTRAST

Reference: VESA FPDM Flat Panel Display Measurements, Sections 303-2, page 55.

Contrast modulation, Cm, of grilles exceeds 65%, and contrast ratio exceeds 5:1 for n x n grilles, n = 3, 2, 1 pixels. Area luminance of grilles is 111.1 ±0.2 fL, and does not vary with increasing spatial frequency.

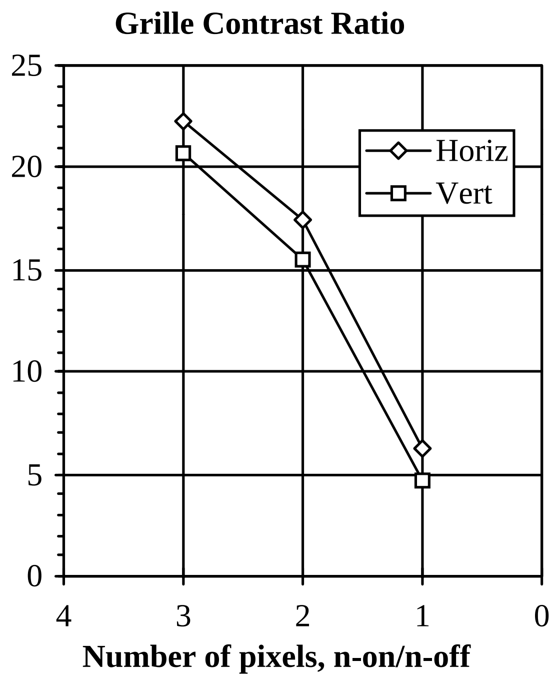
Contrast modulation was measured in both horizontal and vertical directions at screen center for white. The screen luminance was set to 100% of maximum level (226 fL), and the screen background was set to the minimum level (2.7 fL). Three video modulation frequencies were examined using grille test patterns consisting of alternating lines with n pixels on, n pixels off (n=1,2,3). Grille contrast ratios and modulations are determined for filtered luminance profiles using 1-pixel wide moving window average. CCD lens flare was compensated in the measurement using the replica mask method outlined in the VESA FPDM standard referenced above.

The data are displayed in Table II.M-1 and shown graphically in Figures II.M-1 through II.M-3. The contrast modulation, Cm, is reported (the defining equation is given in the table). The Cm is 91% for the horizontal and vertical 3-on/3-off grilles, and 88% or greater for the 2-on/2-off grille. Contrast modulation (HxV) for 1-on/1-off grille patterns was 72% x 65% at screen center and, because this is a fixed-pixellated direct-view display, is presumed not to vary significantly across the screen.

Table II.M-1. Contrast Modulation

Contrast Modulation (in %) at screen center for three spatial frequencies.
Screen luminance at 100% Lmax.
n x n indicates lines n pixels wide separated by n-pixel spaces (n-on / n-off).
V-grille = modulation in horizontal direction (vertical bars);
H-grille= modulation in vertical direction (horizontal bars).
Contrast Ratio, CR = Lpeak/Lvalley
Contrast Modulation, Cm = (Lpeak - Lvalley)/(Lpeak + Lvalley)
Grille contrast ratios and modulations are determined for filtered luminance profiles using 1-pixel wide moving window average as shown in Figure II.M-2.

Grille	Contrast Ratio		Contrast Modulation		Average Luminance (fL)	
n-on/n-off	Horiz	Vert	Horiz	Vert	Horiz	Vert
3	22.2	20.7	91%	91%	111.3	111.3
2	17.5	15.4	89%	88%	110.9	110.9
1	6.2	4.7	72%	65%	111.2	111.1



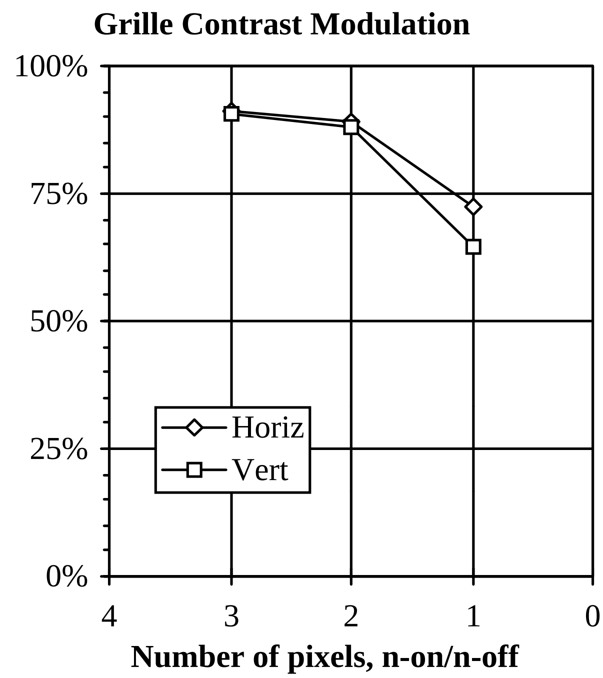


Figure II.M-1. Horizontal and Vertical Grille Patterns
Measured at Screen center.

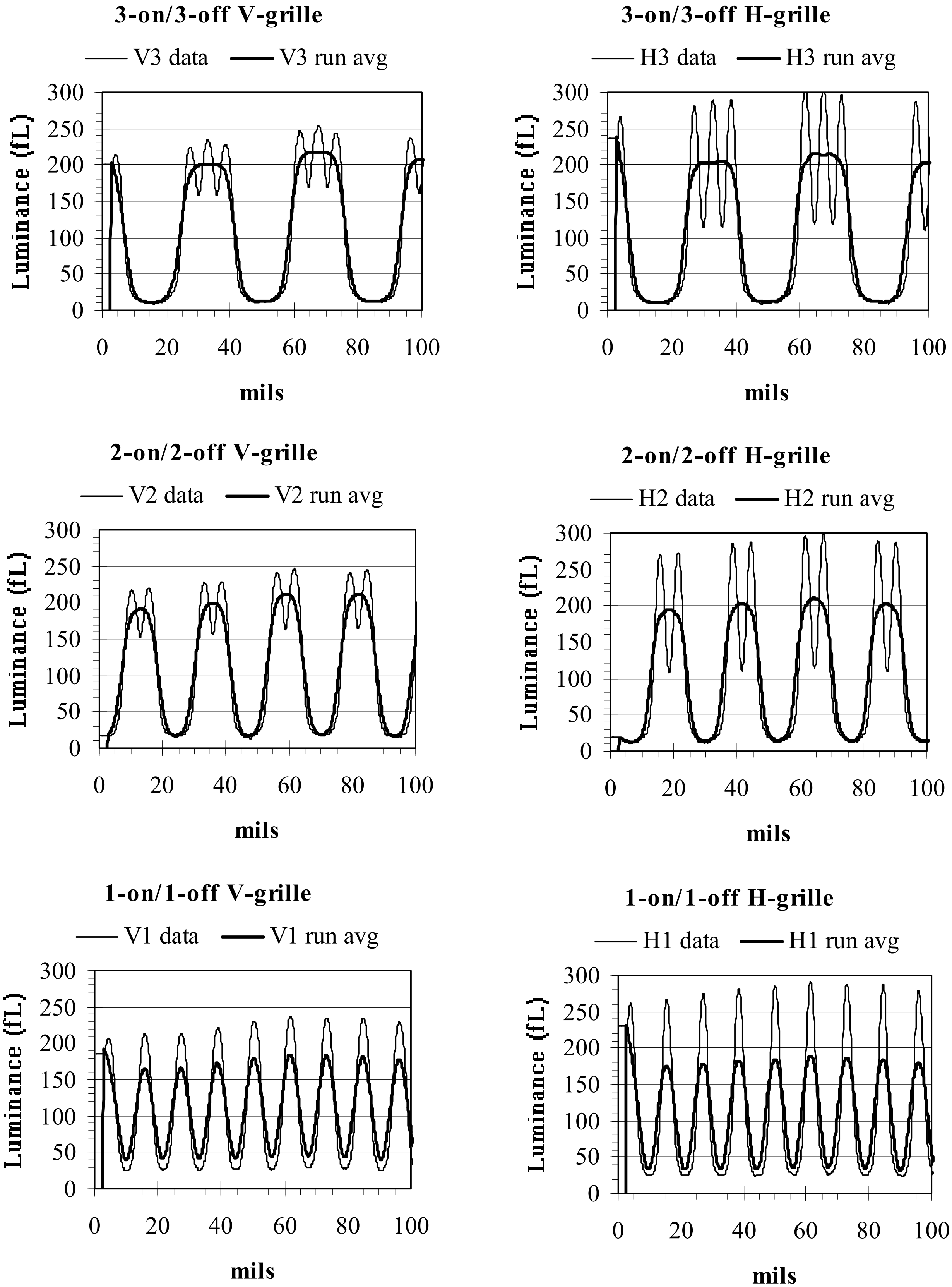


Figure II.M-2. Luminance Profiles in fL of Horizontal and Vertical Grille Patterns Measured at Screen Center.

N. SCREEN REFLECTANCE and AMBIENT CONTRAST

*Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.5, page 31.**
VESA FPDM Flat Panel Display Measurements, Sections 308-1,-2, page 117.

The measured screen reflection factor was 17.1% (no antireflection coating) for directed hemisperical reflectance including specular, haze, and diffuse components. Full screen white-to-black contrast ratio measured perpendicular to screen center decreased from 83.7:1 in a dark room to 51.3:1 in 500 lux diffuse ambient illumination.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simutaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in Figure II.N-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by a screen-sized integrating hemisphere simulated using a polystyrene ice chest. Luminance is measured using a spot photometer with 1° measurement field and a 90% reflective white card as depicted in Figure II.N-1. The measured values and calculated reflectances are given in table II.N-1.

Table II.N-1. Directed Hemispherical Reflectance Data

Luminance measured on screen, L	15.97 fL
Luminance measured on white diffuse reflectance standard card , Lstd	86.33 fL
Known reflectance of standard card, pstd	0.925
Directed hemispherical reflectance of screen, DHR = pstd L/ Lstd	17.1%

Contrast ratio of full screen white-to-black was measured under diffuse ambient lighting conditions using the same set-up as DHR except with the display powered ON. The reported results for ambient contrast ratio are scaled in Table II.N-2 to represent the performance expected in a brightly lit office of 500 lux illumination. Full screen white-to-black contrast ratio measured perpendicular to screen center decreased from 83.7:1 measured in a dark room to 51.3:1 in 500 lux diffuse ambient illumination. Figure II.N-2 illustrates the impact of ambient illumination on the contrast of the display. Figure II.N-3 shows the same relationship for contrast ratio expressed as dynamic range in dB using the following relationship:

$$\text{Dynamic range, dB} = 10 \log CR$$

Table II.N-2. Ambient Contrast Data

Meas.	Lw	221.2 fL	760 cd/m2
Meas.	Lb	2.732 fL	9.38 cd/m2
Meas.	L'w	239.7 fL	823 cd/m2
Meas.	L'b	3.426 fL	11.8 cd/m2
Calc.	Lsw	18.5 fL	63.5 cd/m2
Calc.	Lsb	0.694 fL	2.38 cd/m2
Meas.	Law	249.9 fL	858 cd/m2
Meas.	Lab	12.89 fL	44.3 cd/m2
Calc.	Lrw	10.2 fL	35.0 cd/m2
Calc.	Lrb	9.464 fL	32.5 cd/m2
Meas.	Lstd	251.65 fL	864 cd/m2
Known	pstd	0.925	0.925
Calc.	E		2935 lux
Adjust for ambient	EL		500 lux
Calc.	k		0.1704
Calc.	LAW		766 cd/m2
Calc.	LAB		14.9 cd/m2
Ambient Contrast	CA		51.3

VESA Reflectance and Ambient Contrast

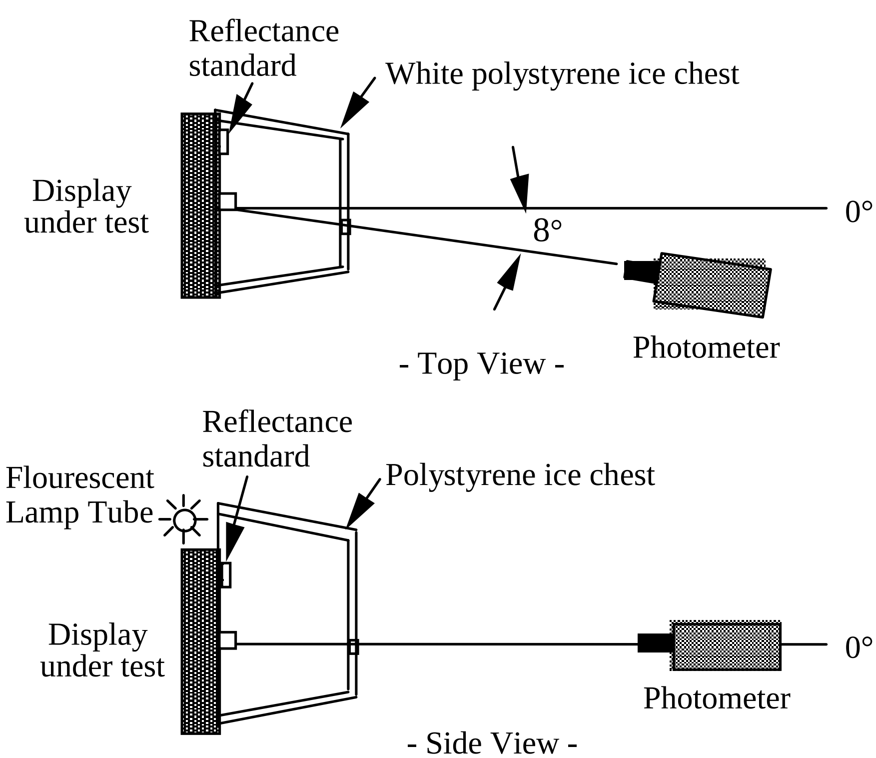


Fig. II.N-1. Test setup for total reflectance and ambient contrast measurement.

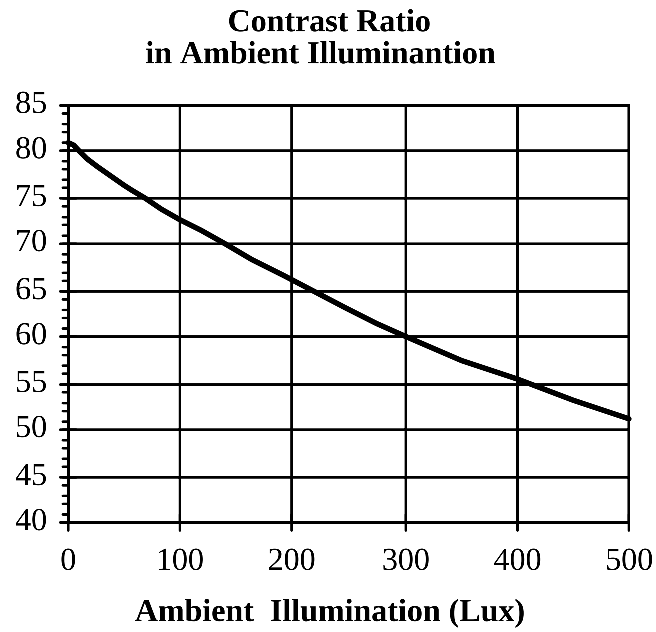


Fig. II.N-2. Contrast ratio of white to black is 51.3:1 in 500 Lux ambient illumination

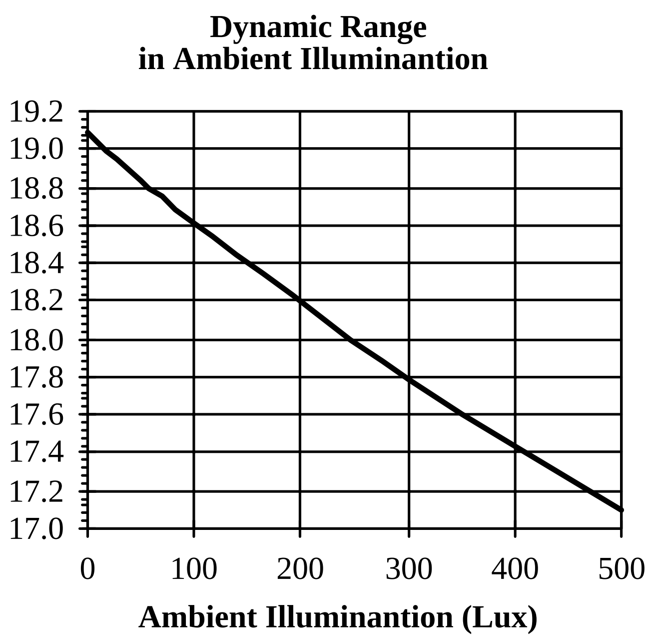


Fig. II.N-3. Dynamic range of white to black is 17.1 dB in 500 Lux ambient illumination

O. DEFECTIVE PIXELS

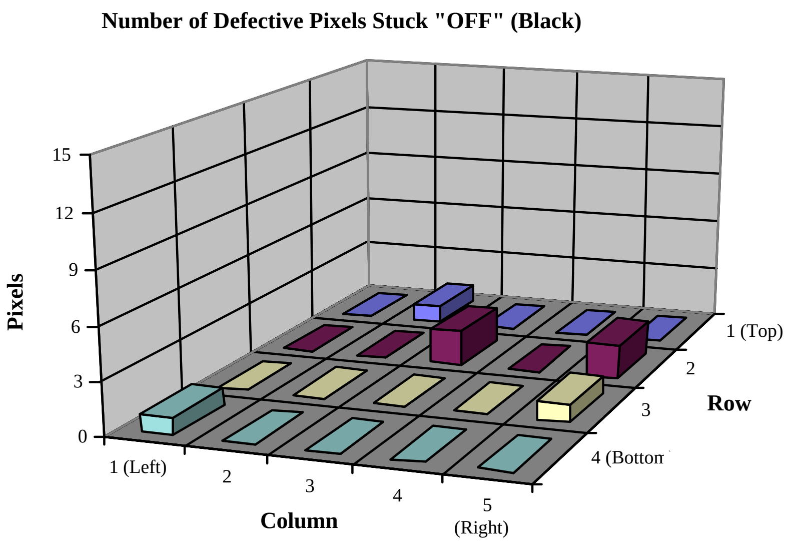
Reference: VESA FPDM Flat Panel Display Measurements, Sections 303-6, page 63.

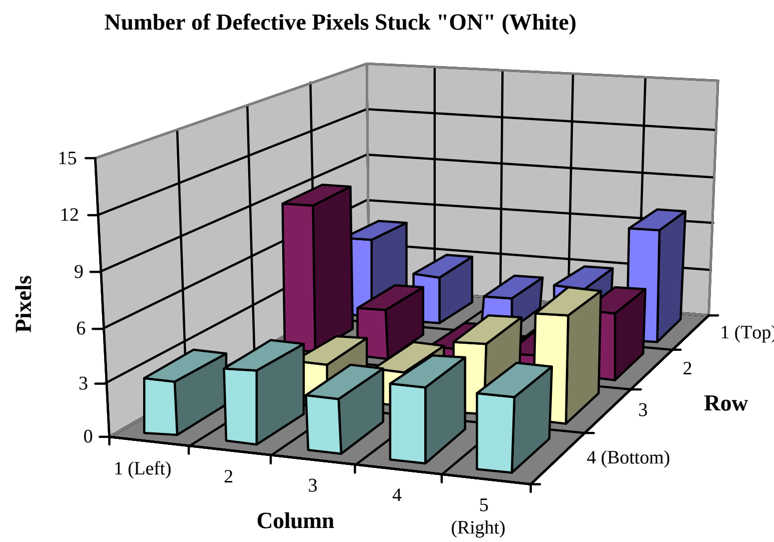
233 stuck pixels, 3 defective pixel clusters, and 2 line defects were identified.

Defective pixels were identified and counted in each of 20 zones on the screen divided into a 5 x4 (H x V) grid. Each defective pixel was judged to be either stuck ON, stuck OFF, or stuck GRAY. Several defective pixels grouped within close proximity of one another were further counted as clusters. Only one line defect was identified.
The defect count data are listed in Table II.O-1 and graphed in Figure II.O-1.

Table II.O-1. Defect Summary.

	Row	White	Black	White	Black	White	Black	White	Black	White	Black
Stuck on	1		5		3		2		3		7
	2		9		3		1		1		4
	3		1		2		2		4		6
	4		3		4		3		4		4
Stuck off	1	0		1		0		0		0	
	2	0		0		2		0		2	
	3	0		0		0		0		1	
	4	1		0		0		0		0	
Stuck gray	1	1	1	1	1	1	1	0	5	1	9
	2	1	4	1	3	3	7	4	5	3	6
	3	0	5	0	6	2	7	1	6	1	7
	4	0	13	0	15	0	9	3	8	3	11
Clusters	1										2
	2		4								
	3										2
	4		2								
NOTES:		COL 5 ROW 1 CLUSTER 2-ON									
		COL 1 ROW 2 CLUSTER 4-ON									
		COL 1 ROW 5 CLUSTER 2-ON									
		Vertical Line stuck at about column 320 (rows 0 to 1840) Approx. 90% of column									





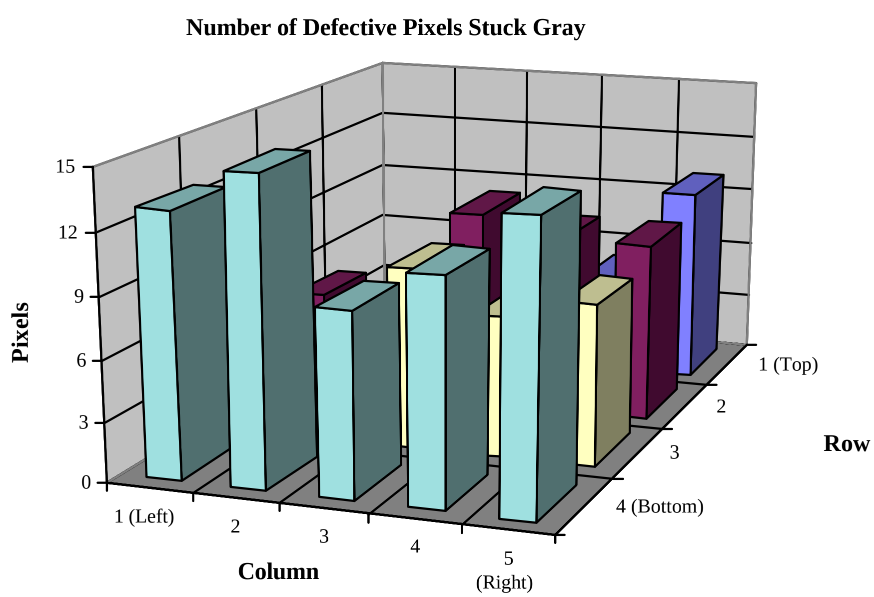


Fig. II.O-1. 233 stuck pixels total were counted across the screen. The number of defective pixels are shown graphically above by location on the screen divided into a 5 x 4 grid.

This page intentionally left blank.

Section III ANALYSIS AND CONCLUSIONS

Advantages

A very high luminance (226 fL) is generated at the highest luminance setting of 255 counts (white full screen). The uniformity of luminance (18% variation across the screen) and chromaticity shift (less than 0.005 $\Delta u'v'$ units) are also very good in comparison to many CRT displays.

Luminance loading effects are not a problem with only 7.2% maximum change in target luminance as the target size is decreased from full screen to 5% of full screen size.
The system tonal transfer characteristic (viewed perpendicular to the screen) is acceptable, exhibiting no black level clipping nor white level saturation. No flicker sensation was observed at the 71 Hz refresh rate. All addressed pixels, excluding about 233 (0.005%) defective pixels, are extremely well resolved, exhibiting contrast modulation, Cm, of grilles exceeding 65%. Unlike CRT displays with video bandwidth limitations, area luminance of grilles does not vary with increasing spatial frequency. Halation was a maximum of only 0.7% on a small black patch surrounded by a large full white area. No shadowing or crosstalk effects were visible on this dpiX display, consistent with most other AMLCDs.

Disadvantages

The high luminance level for black (2.7 fL) limits the dynamic range of the display despite the high luminance achieved for the white full screen (226 fL). The maximum dynamic range of 19.2 dB fails the 25.4 dB minimum requirement proposed by IEC. Screen luminance variations drop the range to 18.5 dB at some screen locations. The best white to black contrast ratio, CR, was 150:1 (21.8dB) when viewed from a horizontal angle, $\theta h = 20°$, and vertical angle , $\theta v = -24°$. Full screen white-to-black CR measured perpendicular to screen center was only 83.7:1, decreasing further to only 51.3:1 in 500 lux diffuse ambient illumination resulting from effects of screen reflections. The screen reflectance factor was measured to be 17.1% total reflectance for combined specular, haze, and diffuse components. Inversion of gray scale levels with small changes in viewing angle severely restricts the screen area that can be exploited without significant eyeball translation..

Response time is typical of AMLCD technology, and so, this LCD probably cannot be used for sequentially-scanned stereo viewing. 22mS rise time of black to white may be prohibitively slow to avoid ghosting in stereoscopic images displayed at 120 Hz field rate. Fall time of white to black was 4 mS and is not considered problematic. Residual (Latent) Image: may be problematic. A white-on-black 60-minute burn-in causes residual image retention amounting to a 10% increase in luminance of black. The increase in luminance stabilizes to within 0.5% after 20 minutes. Previous images take up to a 20 minute relaxation period to fully extinguish

Viewing angle range is rather limited. To maintain white to black contrast ratio of at least 40:1, limit chromaticity shift $\Delta u'v'$ less than 0.015, and eliminate grayscale inversion between Level 255/level 221 (Lmax/91%Lmax) and between Level 017/level 000 (2.6%Lmax/Lmin) , the total useable viewing angle range is limited to $\theta h = \pm 20°$

and θv = ± 10°, spanning 47% of the total area of the screen at a viewing distance of 18 inches.

Table III - 1 Performance Comparison

Comparison of the dpiX monochrome AMLCD and four color AMLCD monitors measured by NIDL. The dpiX monochrome, dpiX color DC1941, and NEC LCD2000 are current generation (1998) wide-angle viewable monitors. The NEC LCD300 and Pixelvision PV116SX are earlier generation monitors.

Parameter	NEC Color LCD300		Pixelvision Color PV116SX		NEC Color LCD2000		dpiX Color DC1941		dpiX Monochrome	
Screen Size	13"		16"		20”		19"		19"	
Addressability	1280x1024		1280x1024		1280x1024		1280 x 1024		2560 x 2048	
Resolution	1280x1024		1280x1024		1280x1024		1280 x 1024		2560 x 2048	
Luminance (ft-Lam)										
White	56.6		36.1		36.6		72.9		226	
Black	0.238		0.147		0.146		0.2		2.7	
Contrast Ratio (CR)	238		246		251		364		83	
Chromaticity	x	y	x	y	x	y	x	y	x	y
White	.332	.351	.312	.360	.272	.313	.333	.333	0.339	0.338
Red	.615	.343	.630	.342	.592	.348	.637	.337	n.a.	n.a.
Green	.315	.552	.295	.614	.299	.564	.302	.604	n.a.	n.a.
Blue	.160	.147	.139	.124	.149	.120	.145	.093	n.a.	n.a.
Gamma	2.46		2.17		2.84		3.4		1.62	
Gamut Area Inside Sprectrum Locus	18%		24%		20%		28%		n.a.	
Black-level Clipping	No		No		Yes		No		No	
Luminance Uniformity (%)	16		24		19		13		18	
Viewing Angle (degrees for CR=20) Vertical										
Up	16		19		>50		43		31	
Down	22		32		>50		46		41	
Horizontal										
Right	45		40		>50		>50		40	
Left	46		40		>50		>50		42	
Gray-Scale Inversion	Bright	Dark	Bright	Dark	Bright	Dark	Bright	Dark	Bright	Dark
Vertical (degrees)										
Up	32	>45	25	>45	>45	>45	31	>50	10	>50
Down	>45	4	>45	15	>45	>45	>50	-11	>50	-26
Horizontal (degrees)										
Right	>45	32	>45	21	>45	>45	>50	>50	>50	>50
Left	>45	31	>45	21.5	>45	15	>50	>50	>50	>50

APPENDIX A DEFINITIONS - Measurement Terms

Addressability: The number of locations in horizontal and vertical directions at which a picture element (pixel) can be displayed.

Contrast Modulation: A measure of relative luminances, L_{peak}, L_{valley}, over a distance of multiple cycles of high and low states in a displayed grille test pattern.

Monitors with contrast modulation greater than 25% are generally acceptable for the display of images while the display of text generally calls for contrast modulation greater than 50%.

Resolution: Measure of the ability to delineate picture detail; i.e., ability to distinguish two adjacent spots on the screen.

System Gamma: The slope of the curve in a log-log plot of output luminance vs. input drive *at the monitor terminals.* Note that this definition includes any modification to the drive curve by the internal boards on the monitor – thus the term *System Gamma.*

Response Time: A measure of how fast a pixel can turn on and turn off.

Flicker: Perceptible temporal variation in luminance.

Line Contrast: Ratio of luminances of a single-pixel line and its background.

Line luminance: Luminance of a single-pixel-wide line

Residual (Latent) Image: Partial remains of an image after the original image has been electronically removed.

Halation: Light leakage from bright areas of an image into the darker areas. Phenomenon by which the luminance of a given region of the screen is improperly increased by contributions from surrounding more luminous areas. Halation is undesirable as it degrades the contrast of displays.

Resolvable pixels: Measure of display resolution. The ability to delineate picture detail; i.e., ability to distinguish two adjacent spots on the screen.

Reflectance: A measure of the tendency for incident luminous flux to be redistributed into the hemispherical area in front of the display screen.

Shadowing or crosstalk: Cross-coupling between pixels

Defective pixels:	Pixels that operate improperly or not all all (stuck).
Luminance Stability (Regulation) vs. Fill Factor:	Measure of variation in luminance as a function of the fraction of screen area that is being lit.
Anomalous nonuniformities:	Worst-case nonuniformity including all areas of the image, not limited to sampled points .
System Tonal Transfer:	Output luminance as a function of input drive.
Ambient Contrast ratio:	Contrast ratio under conditions of illumination, e.g., office lighting (500 lux).
Contrast ratio:	Luminance ratio of black to white.
Four-point viewing angles:	Four viewing directions relative to the perpendicular direction: two vertical angles up and down; two horizontal angles left and right, at which optical properties are specified.
Threshold H & V viewing angles:	Four viewing angles: up, down, right, and left at which arbitrarily-defined values of optical properties such as luminance occur.
Viewing cone thresholds:	360 degree polar plot of a locus of points on a two-dimensional curve identifying viewing directions corresponding to a constant values of an optical properties such as luminance.
Grayscale inversion viewing cone:	360 degree polar plot of a locus of points on a two-dimensional curve identifying viewing directions corresponding to contrast ratio = 1 between two specified gray levels.
Total Viewing Angle:	Viewing angle range over which a display performs adequately for all performance parameters including contrast ratio, gray scale inversion, and chromaticity shift.
Warmup Characteristic:	Time required for the luminance to stabilize at some predetermined value (typically ±1%).

APPENDIX B COLORIMETRY AND CIE COORDINATES

This brief introduction to colorimetry explains usage of certain terms in the present report. For further details, refer to the texts listed below, especially VESA (1998).

In this report, measurement values for display colors are typically presented in 1931 CIE x,y chromaticity coordinates (Fig. B-1). This space does not include luminance, and is not visually uniform: colors equally spaced on the CIE diagram are not seen as equally different. Therefore, in 1976 the CIE (International Commission on Illumination) standardized two color spaces as perceptually uniform, and that incorporate the third dimension of luminance (Wyszecki and Stiles, 1982, pp. 165-166). Of these, the CIELUV space is particularly appropriate for monitor performance, because it is based on a chromaticity representation (u', v') in which an additive mixture of two primary colors (e.g., from phosphors) lies on the line between the primaries.

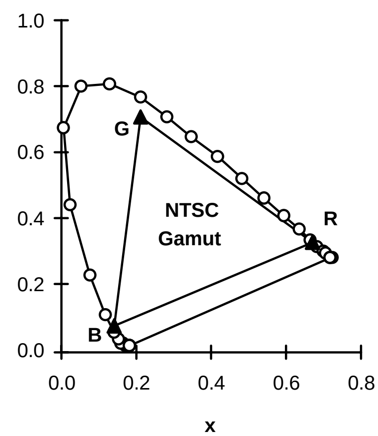


Fig. B-1 CIE 1931 x,y diagram showing the gamut of the NTSC phosphor set. The horseshoe-shaped curve is the locus of monochromatic lights.

Table B-1
Chromaticity Coordinates and Correlated Color Temperatures for Some Common White Points

CIE Illuminant	Correlated Color Temp (K)	CIE 1931 x,y Chromaticity Coordinates x	y	CIE 1976 *u'*,*v'* Chromaticity Coordinates *u'*	*v'*
A	2856	0.448	0.407	0.256	0.524
B	4874	0.348	0.352	0.214	0.485
C	6774	0.310	0.316	0.201	0.461
D_{55}	5503	0.332	0.348	0.204	0.481
D_{65}	6504	0.313	0.329	0.198	0.468
D_{75}	7504	0.299	0.315	0.193	0.459
D_{93}	9300	0.283	0.297	0.189	0.446

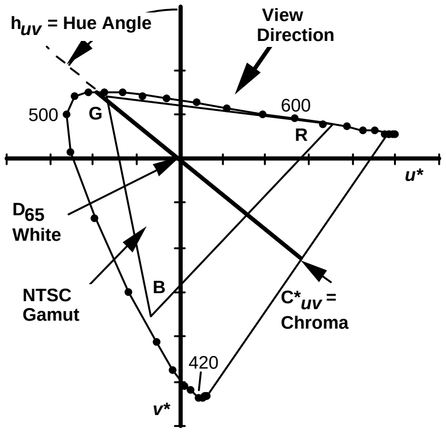


Fig. B-2. The u^*,v^* plane centered on the D65 white point showing the NTSC gamut.

The u',v' chromaticity diagram (see Figure B-2) is obtained from x and y by

$$u' = 2x / (6y - x + 1.5)$$

$$v' = 4.5y / (6y - x + 1.5) \ .$$

Chromaticity differences at equal luminance are described in Δ u'v' units:

$$\Delta\ u'v' = [\Delta\ u'^{\,2} + \Delta\ v'^{\,2}]^{1/2} ,$$

where the Δ 's are the differences between two colors being compared.

Coordinates for the full CIELUV 3-space depend on u', v' , and luminance. The Euclidean distance in this space is a good measure of perceptual difference for spots of angular subtense about 2 degrees of visual angle. However, for assessing spatially gradual nonuniformities on a screen, the Δ u'v' difference is more appropriate, because humans are more sensitive to chromaticity differences than to luminance differences when at low spatial frequencies. The CIE (see Alessi, 1994) has adopted the standard that 0.004 Δ u'v' unit corresponds roughly to a just noticeable difference; two equiluminous colors closer than that are indistinguishable.

The white point of a display, mentioned above, is frequently quantified in terms of its correlated color temperature (CCT). defined as the temperature (in kelvin) of the black-body radiator whose chromaticity is closest to the chromaticity of the white point, as measured in the 1960 CIE (u,v) uniform chromaticity space (see VESA, 1998). The 1960 space is a precursor of u',v' that is kept in the CCT definition for consistency of description over time.

To illustrate the use of these definitions, typical white points are listed in Table B-1 along with their correlated color temperatures, (x,y) coordinates, and (u',v') coordinates. It should be noted that Illuminant C is the NTSC standard white and D_{65} is the PAL standard.

References:

- P. J. Alessi, *Color Res. Appl.* **19**, 48-58 (1994).
- G. Wyszecki and W. S. Stiles, *Color Science* , 2nd Ed, Wiley, New York, 1982.
- VESA (Video Electronic Standards Association), *Flat Panel Display Measurement Standard,* Version 1.0, May, 1998, Section A201.